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The labour market: details matter

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Abstract

In this paper, I introduce labour market mechanisms used in partial equilibrium models, microdata econometric studies, and research in psychology and sociology to an agent-based macroeconomic model. These mechanisms include skill-based worker switching, skill loss during unemployment, and the skill-dependence of wages. I show that when a large supply shock occurs, these complexities prevent GDP from fully recovering, at least in the medium term: the GDP gap between the shock and no-shock scenarios persists even five years after the shock, whereas no such difference is observed in the baseline model. I also show that the aggregate modelling shock affects different industries differently, and this effect is statistically significant depending on the level of skills required in a given industry. Finally, I demonstrate that training programmes for new workers in just the two most affected industries have a comparable impact to training a much larger number of workers with no industry-specific constraints.

Keywords: Agent-Based Modelling, Simulation Modelling, Labour Market Frictions, Human Capital, Labour Mobility, Wages, Employment, Formal Training Programmes, Learning by Doing, Skill, Retraining, Skill Based, Career Change, Occupational Mobility, Job Search, Retraining Programme

***JEL* codes:** C63, J24, J31, J62, J63, J64, J68

1. Introduction and literature review

Agent-based models have been successfully used as tools for labour market research (Neugart, 2008; Horvath et al., 2024). Their high degree of heterogeneity, flexible structure, and extensive ability to test the effects of various government programmes make them very convenient tools for answering questions related to this market.

However, the vast majority of these models consider the labour market without regard for other macroeconomic variables. This seriously limits our understanding of the impact of labour market complexity on indicators not directly related to this market (GDP, inflation), as well as the impact of processes not initially related to it on the labour market itself.

Since the 2008 crisis, work has also been underway to incorporate labour market complexity into core central bank models such as DSGE models. However, the underlying assumptions of these models (homogeneity, anchoring to a single equilibrium, and rational expectations) significantly complicate this process. Agent-based models (ABMs), which are essentially heterogeneous, nonlinear models of general disequilibrium, appear to be a more suitable candidate for modelling the relationship between the macroeconomy and the labour market. Although there are currently only a limited number of studies using large-scale ABMs with the labour market, recent advances in computing speed, allowing such models to be run even on personal computers, are significantly advancing this field.

A comprehensive and recent review by Neugart and Richiardi (2024) reveals the potential of ABM models, including for labour market research. Dawid et al. (2009) analyse the effects of various skills-enhancing policies in a large-scale ABM for the EURACE European economy, incorporating geographic and skill-based heterogeneity. Dawid (2012) also studies the impact of various labour market integration policies on the economic performance and convergence of two different regions in an agent-based model and shows that different labour market integration policies lead, through different regional labour flows, to different regional distributions of specific skills. Poledna et al. (2024) consider the potential economic and labour market consequences of a hypothetical migration scenario inspired by the Austrian experience in 2015 using an MABM calibrated on a large set of micro- and macro-data.

The current study contributes to this literature. Inspired by works in economics, sociology, and psychology exploring various labour market mechanisms, I implement these mechanisms in a large-scale MABM calibrated for Russia and, in this context, analyse the consequences of a supply shock on gross domestic product.

One of the key issues related to the labour market is occupational mobility. Within the ABM framework, this issue is typically examined in the context of the relationship between labour mobility and productivity (see, for example, the work of Wright et al. (2018) and Braunerhjelm (2020)). Basu et al. (2024) show that increased labour mobility leads to increased aggregate output and welfare, and vice versa.

Neugart (2008) develops a labour market model in which each industry requires specific skills and workers can change industries if their skills are sufficient. The author uses this model to examine the effects of public training policies. He shows that public training programmes reduce aggregate unemployment in the economy and also identifies several other labour market regularities. The assumption that worker mobility depends on skills is consistent with the results of a recent empirical study by Helm (2020) using German data. The author confirms the existence of worker flows between firms during trade shocks and that these flows are particularly large for firms operating in the same sector.

In this paper, I use Neugart's (2008) idea of firms with sector-specific skill requirements and implement it in an MABM. Data from the large-scale Cedefop European skills and jobs survey (ESJS) allows for a realistic calibration of the skills required across industries.

Other important issues include the loss of skills during unemployment and the associated wage losses upon returning to work and the difficulty of finding employment after a period of unemployment.

Mincer and Ofek (1982) show that real wages upon returning to work after unemployment are lower than those at the time of exiting the labour force, and this decline is greater the longer the interruption. Furthermore, wages recover relatively quickly upon returning to work, reflecting the recovery of skills upon reemployment. Jarosch (2021) models a frictional labour market in which each job varies in productivity and the likelihood of job termination (reverse job security). Based on this model, the author shows that the loss of job security and its interaction with the evolution of human capital underlie the unemployment scar. Aaronson et al. (2010), using individual data from the Bureau of Labor Statistics survey, show that high levels of long-term unemployment tend to persist into economic recovery, as firms tend to hire the long-term unemployed last. Using Swedish data, Edin and Gustavsson (2008) find statistically strong evidence of a negative relationship between job interruptions and skills. Pissarides (1992) shows that when unemployed workers lose some of their skills, the effects of a temporary shock on employment can persist for a long time. Ljungqvist and Sargent (2008) discuss the differences in unemployment rates in the United States and Europe. The authors conclude that the persistently higher unemployment in Europe after the 1980s is associated with higher skill loss among newly laid-off workers and more generous unemployment compensation. Skill loss also explains why American workers have experienced greater earnings volatility since 1980 and why, especially among older workers, job insecurity rates in Europe now fall sharply with increasing unemployment duration.

Cohen et al. (2025) find no decline in skills among the unemployed using German and American data, but they do find a consistent correlation between the duration of unemployment and the difficulty of finding a new job. The data on which the study is based include fairly basic skills: mathematical skills, verbal fluency, as well as conscientiousness, locus of control, patience, teamwork, risk-taking, and social trust. However, as the ESJS survey shows, many industries require more specific skills, such as implementing new approaches or using digital mechanisms at work, the loss of which may be the primary reason for difficulty in reemployment.

In the context of occupational mobility and the loss of unused skills, the question arises of what happens to skills when a worker changes industries. Although, to my knowledge, no studies have analysed the relationship between industry change and skill changes for adult workers, several related research streams suggest this mechanism is at work.

First, the phenomenon of skill ‘devaluation’ and ‘recovery’ (Mincer and Ofek, 1982) shows that unused skills are forgotten (although in this paper this applies to a period of unemployment, it is likely also present when employment sectors are changed) and then quickly recovered upon returning to work (in this context, it seems logical to assume that skills may not only be recovered but also increased if these skills are used more intensively in the new place of employment than in the previous one). Second, there is a wealth of work demonstrating the success of internship programmes (on-the-job training) (see, for example, the work of Nguyen et al. (2020), Baert et al. (2021), and Villasenor and Cunningham (2014)), which also emphasises the importance of practical experience. Third, there are a number of studies emphasising the importance of the adaptation process (see, for example, the work of Mosquera and Soares (2025) and Frögéli et al. (2023)).

Based on all the work described in this section, I identify several important labour market properties that I incorporate into the model. First, I assume a decline in skills during unemployment and their subsequent recovery upon returning to work. Furthermore, learning from experience and the adaptation process lead to workers increasing the skills that are actively used by the firm and partially losing those skills that are not used. Second, I introduce a dependence of workers' wages on their skills. Furthermore, I identify two hypotheses for testing. First, I assume the existence of unemployment scars for GDP, that is, a significant difference between the GDP trajectories with and without a shock, which will persist even after the shock has passed. Second, I assume that job training programmes for the unemployed can help mitigate this difference.

One of the important advantages of ABMs is the ability to perform detailed industry analysis. While there are numerous studies that analyse the impact of shocks on specific industries, the literature that directly examines differences across industries is limited. Bäurle and Steiner (2015) demonstrate significantly different responses to export shocks across industries using a model for the Swiss economy. Bahal and Lenzo (2023) use panel data for 43 countries to find that industries with a high share of intermediate goods from other industries are more susceptible to various shocks. Thus, the third hypothesis tested in this paper is the differential response of different industries to aggregate shocks. I hypothesise that the differences in industry responses may be related to the labour structure required by the industry. First, the higher the skill level of an industry, the more difficult it is for it to attract workers, simply because the available supply of highly skilled workers in the labour market is limited. If unemployment scars are indeed confined to a few industries, then targeted support for these industries may be more effective than training the unemployed without regard to industry. There is limited research discussing the effectiveness of such programmes. Alfonsi et al. (2020) conduct a labour market training experiment in Uganda and show that vocational training helps improve sector-specific skills and significantly increases employability. Helm (2020) demonstrates that supporting high-tech industries during shocks is more effective for national welfare than supporting low-tech industries. In this paper, I use the model I develop to test the hypothesis about the effectiveness of industry-specific student training programmes, contributing to this literature.

The remainder of the paper is organised as follows: Section 2 describes the structure and calibration of the baseline model; Section 3 describes the labour market complexities introduced into the model and discusses the calibration of this sector; Section 4 describes the experiments conducted and the main results; and Section 5 discusses the robustness of these results to changes in the model parameters; the paper concludes with a discussion of the results obtained and concluding remarks.

2. Base model

In this section, I describe the specification of the model. The model presented in this paper draws heavily on the work of Poledna et al. (2025), but its structure is adapted to the data available for Russia, and it also includes additional mechanisms related to monetary policy.

Sequence of actions

One of the distinctive features of the agent-based approach is that all actions are performed by the agents sequentially. Thus, within each period (quarter), there are several stages (phases) of decision making. In my model, each period contains eight stages, numbered from 0 to 7. Below, I provide a description of the events that trigger these stages. It's also worth noting that the algorithm is designed such that the sequences of actions within a stage, as well as the agents performing these actions, are randomly shuffled each time.

One of the distinctive features of the agent-oriented approach is that all actions are performed by agents sequentially. Thus, within each period (quarter) there are several stages (phases) of decision making. In my model, there are 8 stages within each period, numbered from 0 to 7. Below I provide a description of the events that these stages include. It is also worth noting that the algorithm is designed in such a way that the sequences of actions within a stage, as well as the agents performing these actions, are randomly mixed each time.

0

- The expected rates of inflation and output growth are determined
- The variables described by exogenous processes (AR(1)) are determined: government consumption, imports, and exports
- The commercial bank determines its expected equity

1

- The firms determine their expected profits, free cash flow, and demand for credit
- The firms determine the prices of their goods and the salaries of their employees
- The firms determine the desired volume of production
- The firms determine the demand for the factors of production: labour, investment, and raw materials
- The firms create demand for loans
- The importers determine the prices of their goods
- The importers determine the size of the output
- The exporters determine the demand for goods
- The central bank determines the value of the key rate; the rate on loans is determined as the key rate + a fixed premium
- The government entities determine the demand for goods and services
- The commercial bank determines its expected profit

2

- Interaction between employees and employers occurs in the labour market; the level of employment and unemployment in the current period is determined
- The central bank determines the size of its profit/loss and the size of its equity
- The capital adequacy condition for the commercial bank to issue loans is checked. If the condition is met, the LTV condition is checked for each loan request from the companies, and a decision is made to issue/not issue loans. Approved loans are issued to the companies
- The commercial bank determines its actual profit

3

- The households determine their expected income levels and create consumer demand for goods
- The firms produce goods. The actual level of production ≤ the desired level of production (may be lower if sufficient factors of production cannot be attracted)

4

- Interaction occurs in the product market, and the consumption of goods and services in the economy is determined
- The price indices are calculated
- The firms determine the change in capital taking into account the investments attracted and depreciation

5

- The firms define the change in finished goods inventory as the balance of the goods sold and the goods produced
- The firms determine the change in raw material stocks taking into account the raw materials purchased and used in production
- The firms determine their profits
- The firms determine the change in savings/debt over the period

6

- The households learn their actual income for the period and determine the amount of savings/borrowing (so that income is related to consumption for the period)
- The firms' equity is determined
- The bankruptcy condition of the firms is checked
- The total GDP in the economy is calculated
- The trade balance is calculated

7

- The commercial bank determines the amount of bad debt and writes it off using its equity and funds from the bankrupt firms
- The commercial bank determines the final amount of equity and savings/losses
- The total values of the government are calculated: revenue, budget deficit/surplus, debt

In general, each agent has three types of variables: expectation variables, which are formed before decisions are made and before interactions with other agents are made; key variables, which include active actions; and balance variables, which are calculated as a result of these active actions.

Next, I describe the types of economic agents that the model includes: households, firms, the central bank, the state, a commercial bank, importers, and exporters. It is worth noting that the model contains both nominal and real quantities, which, to avoid confusion, are marked with diacritics as follows: three dots $\dddot{X}$ denote **nominal variables,** while two bars $\bar{\bar{X}}$ denote **real variables.**

Expectations

The process of forming expectations is an important component of agent-based models. Since the agents do not know the future, before they start active actions, they have to form expectations about the future at the current moment and make decisions based on them. At the same time, since this class of models lacks perfect foresight, the agents' expectations may not come true, which entails the emergence of the imbalances characteristic of this approach.

For most agents, following Poledna et al. (2025), I assume that both growth rate expectations and inflation expectations are formed uniformly for all the agents in the economy.

The expected growth rate of the economy γ^e is the weighted average of the actual growth rates for the previous 4 quarters. The initial value for γ is selected based on estimates of the equilibrium growth rate of the Russian economy for 2021 (see the **Calibration** section).

$$\gamma^e(t) = \left(\frac{\gamma(t-4)+\gamma(t-3)+\gamma(t-2)+\gamma(t-1)}{4}\right) \tag{1}$$

The model uses adaptive inflation expectations π^e, which are:

$$\pi^e(t) = \left(\frac{\pi(t-4)+\pi(t-3)+\pi(t-2)+\pi(t-1)}{4}\right) - \omega^{\ddot{r}} * (\ddot{r}(t-1) - \ddot{r}^*) \tag{2}$$

The second term expresses the channel of monetary policy expectations. If the central bank rate is higher than the 'neutral'[1] rate, this signals a tight central bank policy and reduces inflation expectations. On the contrary, a rate lower than the 'neutral' rate indicates a soft policy and increases inflation expectations.

Households

The household sector is modelled and calibrated using Russian population data and includes all the population over 15 years of age. The households are denoted by the index $h \in [0, HH]$. The households have two statuses, one of which is 'work status' (WS), characterising their positions in the labour market – employed (E), unemployed (U), or economically inactive (NA). The second is 'ownership status' (OS), characterising their ownership of a firm or a bank, and can take the forms: owns a firm (IF), owns a bank (IB), or owns neither a firm nor a bank (empty). These two statuses determine the household's income.

Employed households receive wages; unemployed households are paid a fixed unemployment benefit by the state, which is a certain fraction θ^{UB} of their last wages. Each economically active household belongs to a certain occupation (profession), which is determined during the initial calibration of the model and does not change subsequently. A household can work only in a firm whose industry matches its occupation.[2] The occupations for the households are chosen in such a way that the total number of employed and unemployed by industry is consistent with the actual labour market statistics for 2021.[3] The economically inactive households are paid a state subsidy (pension or scholarship). If a household owns a firm, it can receive dividends. This happens if the firm makes a profit and does not make a loss.

Income

The expected wage $\ddot{w}_h^e$, on the basis of which households predict their expected income, is determined by the following formula:[4]

$$\ddot{w}_h^e(t) = \begin{cases} \overline{\overline{w}}_i(t) * P^{HH}(t-1) * (1+\pi^e(t)), if\ hh\ works\ in\ firm\ i \\ \ddot{w}_h(t-1) * (1+\pi^e(t)), \mathrm{WS} = \mathrm{U} \end{cases} \tag{3}$$

where P^{HH} is the CPI.

Subsidies $\overline{\overline{sb}}^{inact}$, paid by the state to the economically inactive households, are determined by the formula:

$$\overline{\overline{sb}}^{inact}(t) = \overline{\overline{sb}}^{inact}(t-1) * (1+\gamma^e(t)) \tag{4}$$

In addition, the government pays subsidies $\overline{\overline{sb}}^{other}$ to all households:

[1] There are several definitions of the neutral rate. For the purposes of this paper, I define the neutral rate as the rate at which monetary policy is neither contractionary nor expansionary.
[2] The 20 industries of the firms, as well as the occupations of the households, are defined in accordance with the OKVED-2 industry classifier.
[3] A detailed discussion of model-to-data fit is provided in the **Calibration** section.
[4] The subscripts characterise the type to which the agent belongs: households ($h \in [0, HH]$), firms ($i \in [0, II]$), the government ($j \in [0, JJ]$), importers ($m \in [0, MM]$), exporters ($l \in [0, LL]$), and the central bank (cb).

$$\overline{\overline{sb}}^{other}(t) = \overline{\overline{sb}}^{other}(t-1) * (1 + \gamma^e(t)) \tag{5}$$

As stated earlier, the households have two statuses, 'work status' and 'ownership status', which determine their income.

So, in my model, the households determine their expected income $\ddot{Y}_h^e$ as follows, depending on their 'work status' and 'ownership status':

$$\ddot{Y}_h^e(t) = \begin{cases} \ddot{w}_h^e(t) + \overline{\overline{sb}}^{other}(t) * P^{HH}(t-1) * \left(1+\pi^e(t)\right), & if\ \mathrm{WS = W, OS = empty} \\ \theta^{\,UB} * \ddot{w}_h^e(t) + \overline{\overline{sb}}^{other}(t) * P^{HH}(t-1) * \left(1+\pi^e(t)\right), & if\ \mathrm{WS = U, OS = empty} \\ \left(\overline{\overline{sb}}^{inact}(t) + \overline{\overline{sb}}^{other}(t)\right) * P^{HH}(t-1) * \left(1+\pi^e(t)\right), & if\ \mathrm{WS = NA, OS = empty} \\ \ddot{w}_h^e(t) + \left(\theta^{DIV} * \max(0, \overline{\overline{P\iota}}_i^e(t)) + \overline{\overline{sb}}^{other}(t)\right) * P^{HH}(t-1) * \left(1+\pi^e(t)\right), & if\ \mathrm{WS = W, OS = IF} \\ \theta^{\,UB} * \ddot{w}_h^e(t) + \left(\theta^{DIV} * \max(0, \overline{\overline{P\iota}}_i^e(t)) + \overline{\overline{sb}}^{other}(t)\right) * P^{HH}(t-1) * \left(1+\pi^e(t)\right), & if\ \mathrm{WS = U, OS = IF} \\ \left(\overline{\overline{sb}}^{inact}(t) + \theta^{DIV} * \max(0, \overline{\overline{P\iota}}_i^e(t)) + \overline{\overline{sb}}^{other}(t)\right) * P^{HH}(t-1) * \left(1+\pi^e(t)\right), & if\ \mathrm{WS = NA, OS = IF} \\ \ddot{w}_h^e(t) + \left(\theta^{DIV} * \max(0, \overline{\overline{P\iota}}_k^e(t)) + \overline{\overline{sb}}^{other}(t)\right) * P^{HH}(t-1) * \left(1+\pi^e(t)\right), & if\ \mathrm{WS = W, OS = IB} \\ \theta^{\,UB} * \ddot{w}_h^e(t) + \left(\theta^{DIV} * \max(0, \overline{\overline{P\iota}}_k^e(t)) + \overline{\overline{sb}}^{other}(t)\right) * P^{HH}(t-1) * \left(1+\pi^e(t)\right), & if\ \mathrm{WS} = U, \mathrm{OS = IB} \\ \left(\overline{\overline{sb}}^{inact}(t) + \theta^{DIV} * \max(0, \overline{\overline{P\iota}}_k^e(t)) + \overline{\overline{sb}}^{other}(t)\right) * P^{HH}(t-1) * \left(1+\pi^e(t)\right), & if\ \mathrm{WS = NA, OS = IB} \end{cases} \tag{6}$$

However, the expected income determined at stage 3 may not coincide with the actual income, which becomes known only at stage 6.

Based on the expectations formed, the household determines its demand for the products of each industry (see the **Consumption** section).

The actual salary $\ddot{w}_h$ is determined by the company and is taken into account by the employee as a given. It is determined as follows:

$$\ddot{w}_h(t) = \begin{cases} \overline{\overline{w}}_i * P^{HH}(t), \text{if } hh \text{ works in firm } i \\ \ddot{w}_h(t-1) * \dfrac{P^{HH}(t)}{P^{HH}(t-1)}, \mathrm{WS = U} \end{cases} \tag{7}$$

Thus, the actual income $\ddot{Y}_h$ of the household is determined as follows:

$$\ddot{Y}_h(t) = \begin{cases} \ddot{w}_h(t) + \overline{\overline{sb}}^{other} * P^{HH}(t), & if\ \mathrm{WS = W, OS = empty} \\ \theta^{\,UB} * \ddot{w}_h(t) + \overline{\overline{sb}}^{other} * P^{HH}(t), & if\ \mathrm{WS = U, OS = empty} \\ \left(\overline{\overline{sb}}^{inact} + \overline{\overline{sb}}^{other}\right) * P^{HH}(t), & if\ \mathrm{WS = NA, OS = empty} \\ \ddot{w}_h(t) + \left(\theta^{DIV} * \max\left(0, \overline{\overline{P\iota}}_i(t)\right) + \overline{\overline{sb}}^{other}\right) * P^{HH}(t), & if\ \mathrm{WS = W, OS = IF} \\ \theta^{\,UB} * \ddot{w}_h(t) + \left(\theta^{DIV} * \max\left(0, \overline{\overline{P\iota}}_i(t)\right) + \overline{\overline{sb}}^{other}\right) * P^{HH}(t), & if\ \mathrm{WS = U, OS = IF} \\ \left(\overline{\overline{sb}}^{inact} + \theta^{DIV} * \max\left(0, \overline{\overline{P\iota}}_i(t)\right) + \overline{\overline{sb}}^{other}\right) * P^{HH}(t), & if\ \mathrm{WS = NA, OS = IF} \\ \theta^{\,UB} * \ddot{w}_h(t) + \left(\theta^{DIV} * \max\left(0, \overline{\overline{P\iota}}_k(t)\right) + \overline{\overline{sb}}^{other}\right) * P^{HH}(t), & if\ \mathrm{WS = U, OS = IB} \\ \left(\overline{\overline{sb}}^{inact} + \theta^{DIV} * \max(0, \overline{\overline{P\iota}}_k(t)) + \overline{\overline{sb}}^{other}\right) * P^{HH}(t), & if\ \mathrm{WS = W, OS = IB} \end{cases} \tag{8}$$

Consumption

As in many agent-based models, my model makes a decision about the demand for consumer goods and services in two stages. In the first stage, the households determine their desired consumption budgets, and in the second stage, they decide how much they are willing to spend on the products of each industry.

The total budget for consumer goods and services of the household C_h^d is directly proportional to the expected income:

$$\dddot{C}_h^d(t) = \frac{\psi^H * \ddot{Y}_h^e(t)}{1 + \tau^{VAT}} \tag{9}$$

The demand for the goods and services $\dddot{C}_{hg}^d$ of specific industry *g* is determined by the formula:

$$\dddot{C}_{hg}^d(t) = \frac{b_g^{HH} * P_g(t-1)}{P^{HH}(t-1)} \dddot{C}_h^d(t) \tag{10}$$

where b_g^{HH} is the weight of industry *g* in consumption and P_g is the price index for industry *g* (see (18)).

The lack of perfect foresight in the model means that the firms do not know the exact demand for their products and may under- or overestimate it.

Therefore, the desired demand of a household $\ddot{C}_h^d$ may not coincide with the actual consumption $\ddot{C}_h$ if the firms are unable to satisfy the demand:

$$\ddot{C}_h(t) \begin{cases} = \sum_g \ddot{C}_{hg}^d(t), & if\ hh's\ demand\ is\ successfully\ met \\ < \sum_g \ddot{C}_{hg}^d(t), & if\ hh\ could\ not\ satisfy\ demand \end{cases} \quad (11)$$

The possibility that household demand will not be satisfied (or will be satisfied incompletely) is one distinctive feature of ABMs compared to DSGE models. In ABM models, households (like firms) have only very limited information and are forced to make assumptions about future supply and demand. These assumptions may be far removed from what actually occurs and create market imbalances.

The lack of complete information among the agents seems a much more realistic assumption, and the technical possibility of market imbalances provides ample opportunities for studying them which are unavailable in the general dynamic equilibrium approach.

The household borrows the resulting shortage or keeps the surplus of funds on deposit. The commercial bank issues the loans or keeps the household deposits, and in this version of the model, for simplicity, it is assumed that the bank issues the loans automatically and does not assess the financial situation of the households.

The total wealth of a household is the balance of its income and expenses and is determined by the formula:

$$\ddot{D}_h(t) = \ddot{D}_h(t-1) + \ddot{Y}_h(t) - (1+\tau^{VAT}) * \ddot{C}_h(t) + \ddot{r}(t) * \max\left(0, \ddot{D}_h(t-1)\right) - \ddot{r}^{loan}(t) * \max\left(0, -\ddot{D}_h(t-1)\right) \quad (12)$$

Firms

The sector of firms is modelled on the basis of real data on the distribution of firms by industry. Each of these firms belongs to one of the 20 industries in the OKVED-2 industry classifier.

Expectations

Once the aggregate inflation expectations and expected growth rates of the economy are determined, the firms determine their own expected values.

The expected profit of the firm Π_i^e is defined as the profit of the previous period, adjusted for the expected growth rate of the economy γ^e and the expected inflation π^e:

$$\ddot{\Pi}_i^e(t) = \ddot{\Pi}_i(t-1) * \left(1+\gamma^e(t)\right) * \left(1+\pi^e(t)\right) \quad (13)$$

The firm determines its expected net cash flow taking into account expected profits, the loan repayment schedule (see the **Firms** → **Loans** section), and dividend payments:

$$\Delta\ddot{D}_i^e(t) = \ddot{\Pi}_i^e(t) - \theta \ddot{L}_i(t-1) - \theta^{DIV} max\left(0, \ddot{\Pi}_i^e(t)\right), \quad (14)$$

where θ is the fraction of debt paid off in each period.

Production

In the model, goods are produced using three factors of production, labour, capital, and intermediate goods, using the Leontief production function:

$$\bar{\bar{Y}}_i(t) = min\left(\bar{\bar{Q}}_i^s(t),\ \beta_i \bar{\bar{M}}_i(t-1), \alpha_i \bar{\bar{N}}_i(t), \kappa_i \bar{\bar{K}}_i(t-1)\right) \quad (15)$$

where $\bar{\bar{Q}}_i^s$ is the desired volume of sales (eq.15), $\bar{\bar{M}}_i$ is intermediate goods (eq.33), $\bar{\bar{N}}_i$ is equations 21–22, actually determined as a result of the search-and-matching process in the labour market, and $\bar{\bar{K}}_i$ is capital (eq.29).

Desired volume of production

Each period, the firms determine the selling prices of their products and the volume of production. Let us first discuss the process of choosing the desired volume of production.

The firm chooses the desired volume of sales $\bar{\bar{Q}}_i^s$ according to the following formula, based on (1) the products offered for sale in the previous period $\bar{\bar{Q}}_i^o$, adjusted for (2) the growth rate of the economy γ^e, and (3) and adjusted for the individual expectations of the firm depending on the dynamics of its output in previous periods:

$$\bar{\bar{Q}}_i^s(t) = (1+\gamma)^{1+t} * \bar{\bar{Q}}_i^o(-1) + \left(\frac{\bar{\bar{Y}}_i(t-1)}{\bar{\bar{Y}}_i(t-2)}\right)^{\lambda} \quad (16)$$

It is worth noting that the model identifies several variables related to the company's sales volume. All of them are designated by the letter *Q* and are distinguished by superscript indices. For convenience, all of these variables are listed below.

Variable	Description	Equation/process that determines
$\bar{\bar{Q}}_i^d(t)$	Actual demand for the products of the *i*-th firm in period *t*	It is determined in the process of interaction between consumers and sellers in the product market (search and matching)
$\bar{\bar{Q}}_i^o(t)$	Firm's output available for sale in period *t*: the amount produced in period *t* plus the balances from previous periods	$\bar{\bar{Q}}_i^o(t) = \bar{\bar{Y}}_i(t) + \bar{\bar{S}}_i(t-1)$
$\bar{\bar{Q}}_i^s(t)$	The amount of output that the firm wishes to produce in the current period. It may be greater than the actual output $\bar{\bar{Y}}_i(t)$ if the firm fails to attract sufficient factors of production.	(16)

This complex system of variables and equations describing the trading process is very specific to ABMs. In standard DSGE models, the entire process is reduced to just a few variables and equations because 1) demand equals supply at any given moment in time; 2) expectations are formed under conditions of complete information, and therefore coincide with reality; 3) all agents have complete information about each other's decision-making processes; and 4) complete predetermination makes the order of the decision-making process unimportant. In an ABM model, these assertions may not all hold. Moreover, all of these points are critical to the definition of the ABM model. For example, while a DSGE model assumes that decisions are made by all agents simultaneously, in an ABM model, all transactions occur sequentially. This creates a sequence of household–firm pairs in which the bargaining process occurs. And this order may be very important, since it determines which households may be unable to purchase desired goods (if demand exceeds supply) or which firms may be unable to sell their goods (if supply exceeds demand). Such decisions may affect not only individual agents but also the aggregate variables, so robust analysis requires that simulations be run for different sequences of such pairs.

Prices

In addition to the volume of output, the company determines the price of its products in each period. The price change is determined by the expected inflation π_i^e and the random shock $\xi_t(t) \sim \mathbb{N}(0,0.005)$.

So, firm i determines the price of its product using the formula:

$$P_i(t) = P_i(t-1) * \left(1 + \pi^e(t) + \xi_t(t)\right) \quad (17)$$

For convenience, the variables that determine certain price indices are presented in the table below.

Variable	Description	Equation	
$P_g(t)$	Product index for industry *g*	$P_g(t) = \frac{\sum_{i \in I_{s=g}} P_i(t)\bar{\bar{Q}}_i(t) + P_{m=g}(t)\bar{\bar{Q}}_{m=g}(t)}{\sum_{i \in I_{s=g}} \bar{\bar{Q}}_i(t) + \bar{\bar{Q}}_{m=g}(t)}$	(18)
P^{HH}	Household price index (CPI)	$P^{HH}(t) = \sum_g b_g^{HH} P_g(t)$	

P^{MAT}	Index for intermediate goods	$P^{MAT}(t) = \sum_g b_g^{MAT} P_g(t)$	
P^{CF}	Capital goods index	$P^{CF}(t) = \sum_g b_g^{CF} P_g(t)$	
P^{JJ}	Price index for government enterprises	$P^{JJ}(t) = \sum_g b_g^{JJ} P_g(t)$	
P_h^{HH}	Price index of the *h*-th household	Calculated based on the actual transactions of the agents	
P_i^{MAT}	Index for the intermediate goods of the *i*-th firm		
P_i^{CF}	Capital goods index for the *i*-th firm		
P_j^{JJ}	Price index for the *j*-th government enterprise		
P_l^{EXP}	Price index of the *l*-th exporting firm		
P^{IMP}	Price index of the *m*-th importing firm		

Demand for labour

The demand for labour is determined by the formula:

$$\bar{\bar{N}}_i^d(t) = max\left(1, integer\left[\frac{min\left(\bar{\bar{Q}}_i^s(t), \kappa_i \bar{\bar{K}}_i(t-1)\right)}{\bar{\alpha}_i}\right]\right) \tag{19}$$

where capital $\bar{\bar{K}}_i(t-1)$ is defined by equation (*26*).

Several considerations are taken into account in determining the demand for labour. First, each firm must employ at least one person. Second, the desired level of production is taken into account in forming the demand for labour. Third, given the use of the Leontief production function, the amount of capital available to the firm (adjusted for the coefficient) is taken into account, since the firm will not be able to produce in excess of this volume in any case.

After determining the desired number of employees, the firm determines $\bar{\bar{V}}_i(t)$, how many employees need to be hired or fired to achieve this desired indicator.

In addition, to smooth out the processes in the labour market and make it function more realistically, I assume that the firms cannot abruptly cut or hire employees. They can hire or fire no more than η% of the total number of employees for the previous period.

$$\bar{\bar{V}}_i(t) = min\left(\bar{\bar{N}}_i^d(t) - \bar{\bar{N}}_i(t-1)\right) \tag{20}$$

To ensure economic growth in the model, I assume that labour productivity grows at the equilibrium rate of economic growth.

$$\bar{\alpha}_i(t) = \gamma * \bar{\alpha}_i(t-1) \tag{21}$$

$$\alpha_i(t) = \bar{\alpha}_i(t) * min\left(1, \frac{\bar{\bar{Q}}_i^s(t)}{\bar{\bar{N}}_i(t)\bar{\alpha}_i(t)}\right) \tag{22}$$

Real wages $\bar{\bar{w}}_i$ are determined by the industry and do not change:

$$\bar{\bar{w}}_i(t) = \bar{w}_g(t), \tag{23}$$

where $\bar{w}_g(t) = \gamma * \bar{w}_g(t-1)$.

The demand for investment $\bar{\bar{I}}_i^d$ is determined in two stages. In the first stage, the total demand for investment is determined based on the desired volume of production and the available volume of labour and is determined by the formula:

$$\bar{\bar{I}}_i^d(t) = \frac{1}{\kappa_i} min\left(\bar{\bar{Q}}_i^s(t), \alpha_i \bar{\bar{N}}_i(t)\right) \tag{24}$$

At the second stage, the demand for the investment goods of each specific industry is determined:

$$I_{ig}^{d}(t) = b_g^{cf} * \bar{\bar{I}}_i^d(t) \tag{25}$$

Like all the other goods in my model, the investment goods are acquired in transactions, so the demand for the goods may be fully, partially, or not satisfied at all, depending on the current economic situation:

$$\bar{\bar{I}}_i(t) \begin{cases} = \sum_g \bar{\bar{I}}_{ig}^d(t), & if\ the\ firm's\ demand\ is\ successfully\ met \\ < \sum_g \bar{\bar{I}}_{ig}^d(t), & if\ the\ firm\ cannot\ satisfy\ demand \end{cases} \tag{26}$$

The dynamics of capital are determined by the capital of the previous period minus the depreciation of capital plus investments:

$$\bar{\bar{K}}_i(t) = \bar{\bar{K}}_i(t-1) - \frac{\delta_i}{\kappa_i}\bar{\bar{Y}}_i(t) + \bar{\bar{I}}_i(t) \tag{27}$$

The demand for additional purchases of intermediate goods is also determined in two stages. In the first stage, the aggregate demand is determined:

$$\Delta\bar{\bar{M}}_i^d(t) = \frac{min\left(\bar{\bar{Q}}_i^s(t), \alpha_i\bar{\bar{N}}_i(t)\right)}{\omega^{MAT}\beta_i} \tag{28}$$

I add the parameter ω^{MAT} to the model, which reflects the process of forming precautionary stocks. Thus, the firms try to maintain a certain buffer stock of intermediate goods to smooth out output, if, for example, the demand for intermediate goods cannot be satisfied in a certain period.

At the second stage, the demand for additional purchases of intermediate goods for each specific industry is determined:

$$\Delta\bar{\bar{M}}_{ig}^d(t) = b_g^{int} * \Delta\bar{\bar{M}}_i^d(t) \tag{29}$$

And, again, demand may be fully, partially, or not satisfied depending on the economic situation:

$$\Delta\bar{\bar{M}}_i(t) \begin{cases} = \sum_g \Delta\,\bar{\bar{M}}_{ig}^d(t), & if\ the\ firm's\ demand\ is\ successfully\ met \\ < \sum_g \Delta\,\bar{\bar{M}}_{ig}^d(t), & if\ the\ firm\ cannot\ satisfy\ demand \end{cases} \tag{30}$$

The final dynamics of intermediate goods are determined based on the stocks of the previous period minus the goods used in production plus the goods purchased in the current period:

$$\bar{\bar{M}}_i(t) = \bar{\bar{M}}_i(t-1) - \frac{\bar{\bar{Y}}_i(t)}{\beta_i} + \Delta M_i(t) \tag{31}$$

Sales

Sales in the model are carried out through sequential interaction between the consumers and producers. The order in which this interaction occurs is determined randomly and changes every period.

As a result of the interaction of the agents, one of the following situations is formed:

$$\bar{\bar{Q}}_i^d(t) \begin{cases} < \bar{\bar{Y}}_i(t) + \bar{\bar{S}}_i(t-1), & if\ demand\ is\ less\ than\ supply \\ = \bar{\bar{Y}}_i(t) + \bar{\bar{S}}_i(t-1), & if\ demand\ exactly\ equals\ supply \\ > \bar{\bar{Y}}_i(t) + \bar{\bar{S}}_i(t-1), & if\ demand\ is\ greater\ than\ supply \end{cases} \tag{32}$$

The change in the stock of finished goods of the firms is determined by the formula:

$$\Delta\,\bar{\bar{S}}_i(t) = (1-\delta^S)\left(\bar{\bar{Y}}_i(t) - \bar{\bar{Q}}_i(t)\right), \tag{33}$$

where $\bar{\bar{Y}}_i(t) - \bar{\bar{Q}}_i(t)$ is the difference between a firm's output and the products actually sold and δ^S is the depreciation coefficient.

The final stock of finished goods in period *t* is determined taking into account the stock of the previous period and the changes in the stocks of products that occurred in the current period. In this case, the change in stocks can be either positive (if the supply exceeded the demand and there are products that have not been sold) or negative (if demand was higher than output and stocks of finished goods have been sold).

$$\bar{\bar{S}}_i(t) = \bar{\bar{S}}_i(t-1) + \Delta\bar{\bar{S}}_i(t) \tag{34}$$

Loans

The firms may demand loans from the commercial bank if they estimate that they need additional financing based on their current and projected future excess/deficit of free cash flow. The demand for loans is determined by the formula:

$$\Delta L_i^d(t) = max\big(0, -\Delta D_i^e(t) - D_i(t-1)\big) \tag{35}$$

The commercial bank makes a positive or negative decision on issuing a loan based on its own capitalisation and an assessment of the reliability of the specific borrower. See the **Commercial bank** section for more detailed information.

The final amount of the company's loan in period t becomes known after the application has been reviewed by the commercial bank and is calculated using the formula:

$$L_i(t) = (1-\theta)L_i(t-1) + \Delta L_i(t) \tag{36}$$

Balance variables

In this section, I describe the variables characterising the financial condition of the firm after all active actions have been completed.

The firm's profit $\Pi_i(t)$ is defined as the firm's sales revenue plus the change in its finished (unsold) product inventories minus the costs of the factors of production and is adjusted for the interest paid on loans or earned on deposits.

$$\begin{aligned}\Pi_i(t) = \underbrace{P_i(t)\bar{\bar{Q}}_i(t)}_{Sales} + \underbrace{P_i(t)\Delta\bar{\bar{S}}_i(t)}_{\substack{Change\ in\ finished \\ goods\ inventory}} - \underbrace{\bar{\bar{w}}_i(t)\bar{\bar{N}}_i(t)P^{HH}(t)}_{Labour\ costs} \\ -\underbrace{\frac{1}{\beta_i}P_i^{MAT}(t)\bar{\bar{Y}}_i(t)}_{Material\ costs} - \underbrace{\frac{\delta_i}{k_i}P_i^{CF}(t)\bar{\bar{Y}}_i(t)}_{Depreciation} \\ -\underbrace{r^{loan}(t) * \big(L_i(t-1) + \max\big(0, -D_i(t-1)\big)\big)}_{Interest\ payments} + \underbrace{r(t) * \max\big(0, D_i(t-1)\big)}_{Interest\ received}\end{aligned} \tag{37}$$

As in the case of the expectations, the same interest rates apply to all the agents in the model. There are three rates in the model: the deposit rate $r(t)$ (which is also the key rate of the central bank), the loan rate r^{loan}, and the government loan rate r^G. This issue is discussed in more detail in the **Central bank** section.

Net cash flow is calculated as all of the firm's revenues minus all of its costs.

$$\begin{aligned}\Delta D_i(t) = \underbrace{P_i(t)\bar{\bar{Q}}_i(t)}_{Sales} - \underbrace{\bar{\bar{w}}_i(t)\bar{\bar{N}}_i(t)P^{HH}(t)}_{Labour\ costs} - \underbrace{P_i^{MAT}(t)\Delta\bar{\bar{M}}_i(t)}_{Material\ costs} \\ -\underbrace{r^{loan}(t) * (L_i(t-1) + \max(0, -D_i(t-1)))}_{Interest\ payments} + \underbrace{r(t) * \max\big(0, D_i(t-1)\big)}_{Interest\ received} \\ - \underbrace{P_i^{CF}(t)\bar{\bar{I}}_i(t)}_{Investment\ costs} + \underbrace{\Delta L_i(t)}_{New\ credit} - \underbrace{\theta L_i(t-1)}_{Debt\ instalment}\end{aligned} \tag{38}$$

The total amount of cash available to a firm is determined as the amount in the previous period plus the net cash flow of the current period.

$$D_i(t) = D_i(t-1) + \Delta D_i(t) \tag{39}$$

It is worth noting that, as in the case of the households, ΔD_i and $D_i(t)$ may be both positive and negative. If the company has free cash ($D_i(t) > 0$), it places it in a one-period deposit in the commercial bank at a rate of $r(t)$, thereby generating additional interest income in the next period. If the company has a cash gap ($D_i(t) < 0$), it closes it with an overdraft from the bank at a rate of r^{loan}.

Finally, the firm's final equity for the period is determined by the formula:

$$E_i(t) = D_i(t) + P^{MAT}(t) * M_i(t) + P_i(t) * S_i(t) + P^{CF}(t)K_i(t) - L_i(t)\ \forall i \in I_s \quad (40)$$

Bankruptcy

The model allows for the possibility of the bankruptcy of firms. In the 6th stage of each period, the fulfilment of the conditions $D_i(t) < 0$ (i.e., insolvency of cash flows) and $E_i(t) < 0$ (i.e., insolvency of the firm's equity capital) is checked. If the conditions are fulfilled simultaneously, the firm is declared bankrupt.

To keep the total number of firms in the economy unchanged,[5] each bankrupt firm is replaced by a new one which inherits its assets and part of its liabilities. This part is determined as the share ζ^b of the inherited capital. The remaining part of the liabilities of the bankrupt firm is written off at the expense of the equity capital of the commercial bank as bad debt.

Thus, the liabilities of the newly created firm in the next period are determined by the formula:

$$L_i(t+1) = \zeta^b P_i^{CF}(t)K_i(t) \quad (41)$$

The firm's net cash flow is zeroed out:

$$D_i(t+1) = 0 \quad (42)$$

The equity of the company established is determined as follows:

$$E_i(t+1) = E_i(t) + (L_i(t) - D_i(t) - \zeta^b P_i^{CF}(t)K_i(t)) \quad (43)$$

Commercial bank

For simplicity, there is only one financial intermediary in the model – a commercial bank, which (1) holds household and firm deposits (2) issues overdrafts to households and firms automatically (i.e., without assessing the financial position of the borrower and possible refusal), and (3) can issue loans to the firms upon request and in compliance with the macroprudential requirements. The bank covers its own cash gaps or surpluses by attracting funds from or placing funds in the central bank.

Expectations

At the beginning of each period, the expected variables of the bank are determined. The bank determines its expected equity capital to check the fulfilment of the macroprudential requirements (see the **Firms → Loans** section). The expected profit of the bank is required to calculate the expected income of consumers (see the **Consumers → Income** section). A naive forecast is used to forecast the bank's equity capital:

$$E_k^e(t) = E_k(t-1) \quad (44)$$

The expected profit of the bank is calculated taking into account the profit of the previous period, as well as the expected future inflation and economic growth rates:

$$\Pi_k^e(t) = \Pi_k(t-1) * \left(1 + \gamma^e(t)\right) * \left(1 + \pi^e(t)\right) \quad (45)$$

Provision of loans

The bank then makes a decision on whether to issue loans. This is based on two macroprudential characteristics. First, the bank checks the adequacy of its own capital. This condition is met if:

$$\frac{E_k^e(t)}{\sum_{i=1}^{I}(L_i^e(t) + \Delta L_i(t))} \geq \xi^{bank} \quad (46)$$

[5] Changing the number of firms in the economy creates many additional effects and requires detailed modelling and verification with real data. This issue is beyond the focus of the current study, so for simplicity, I hold the total number of firms constant throughout the simulations.

If this condition is not met, the bank does not issue loans of this nature. If the condition is met, the bank checks the LTV condition for the specific firm:

$$\frac{L_i^e(t) + \Delta L_i(t)}{K_i^e(t)} \leq \xi^{LTV} \tag{47}$$

If this condition is met, the bank issues a loan to the company.

Balance variables

This section describes the variables that are calculated as the final result of the interaction of the individual agents in the economy.

The bank's actual profit is calculated as the interest income from the firm loans and overdrafts plus the interest income from the household overdrafts minus the interest expenses on the firm and household deposits plus the interest income/expenses on the commercial bank's balances at the central bank.

$$\begin{aligned} \Pi_k(t) &= r^{loan}(t) * \left(\sum_{i=0}^{II} L_i(t-1) + \max(0, -D_i(t-1) \right) \\ &+ r^{loan}(t) * \sum_{h=0}^{HH} \max\big(0, -D_h(t-1)\big) - r(t) * \sum_{i=0}^{II} \max\big(0, D_i(t-1)\big) \\ &- r(t) * \sum_{h=0}^{HH} \max\big(0, D_h(t-1)\big) - r(t) * \max(0, -D_k(t-1)) \end{aligned} \tag{48}$$

The bank's equity is the equity for the previous period plus the bank's profit minus the dividends paid to the household that owns the bank minus the write-off of bad debt.

$$\begin{aligned} E_k(t) &= E_k(t-1) + \Pi_k(t) - \theta^{DIV} \max\big(0, \Pi_k(t)\big) \\ &- \sum_{i=0}^{II^{bankrupt}} \left(L_i(t) - D_i(t) - \zeta^b P_i^{CF}(t) K_i(t)\right), \end{aligned} \tag{49}$$

where $II^{bankrupt}$ is the firms that went bankrupt in the current period.

Government

In the model, the government consists of two parts: the sector of state organisations (which form consumer demand in the market for goods and services) and the aggregated state (whose main function is the redistribution of income, i.e., the collection of taxes and the payment of subsidies).

The government sector is very simple, described by simple AR(1) processes. Public debt is simply a calculable quantity, and it is assumed that the government can borrow indefinitely to meet demand, make social payments, and service existing debt. Studying the stability of public debt, its impact on inflation, and other related issues is a complex, multifaceted, and independent task, lying not only beyond the issues discussed in this paper but also beyond those discussed using the standard DSGE models of central banks.[6]

Government entities

The government entities $j(j = \overline{1, JJ})$ create demand for the goods and services of the firms. The growth rate of government consumption is the 'equilibrium' growth rate of the economy plus a random shock and has the form:

$$\gamma^G(t) = \gamma + sh^{\gamma G} \tag{50}$$

The demand for goods and services is formed in three stages. First, the total demand of the public sector for goods and services is determined:

$$\bar{\bar{C}}_G^d(t) = \bar{\bar{C}}_G^d(t-1) * e^{\gamma^G(t)} \tag{51}$$

[6] There are specific DSGE models used to analyse fiscal policy, typically for the needs of ministries of finance. In these models, unlike those used by central banks, the banking sector is significantly reduced, while the fiscal sector is significantly expanded.

The budget for all goods and services of each individual entity is then determined. I assume no heterogeneity in these organisations, and so each organisation's desired consumption is equal to the total public sector demand divided by the number of organisations *J*:

$$\ddot{C}_j^d(t) = \frac{\ddot{C}_G^d(t) * P^{JJ}(t-1) * (1 + \pi^e(t))}{JJ} \tag{52}$$

Finally, the demand for the product of each specific industry is determined for each organisation:

$$\ddot{C}_{jg}^d(t) = \frac{b^{JJ} * P_g(t-1)}{P^{JJ}} \tag{53}$$

Central bank

The Bank of Russia switched to an inflation targeting policy in 2015. It defined the goal of monetary policy as achieving and maintaining an inflation target of 4% per annum. I use this information to describe the central bank in the model.

The central bank in the model economy performs two main functions. First, it sets the base interest rate in the economy $r(t)$. Second, it is a balance agent in the economy that absorbs surplus or provides additional liquidity, depending on the situation that has developed in the private sector in the current period. In addition, for simplicity, the central bank acts as a creditor to the state. Let us consider these functions in more detail.

The key rate in the economy is determined on the basis of the Taylor rule:

$$\ddot{r}(t) = \bar{\bar{r}}^* + \pi^* + \xi^\pi(\pi^e(t) - \pi^*), \tag{54}$$

where r^* is the equilibrium real interest rate, π^* is the inflation target, and ξ^π is the parameter of the reaction force to the deviation of inflation from the target.

As stated earlier, the central bank performs a balance sheet function in the economy by providing or absorbing liquidity. The central bank's activities are not aimed at generating profit. Its profit is defined as the calculated amount of interest income received on the loans provided and the interest payments paid on the deposits attracted:

$$\Pi^{CB}(t) = r^G(t) * L^G(t-1) - r_t * D_k(t-1) \tag{55}$$

Importers

The growth rate of import supply follows an AR(1) process:

$$\gamma^I(t) = \alpha^{\gamma,I}\gamma^I(t-1) + \beta^{\gamma,I} + \epsilon^{\gamma,I}(t-1) \tag{56}$$

The supply of imports is thus determined by the formula:

$$Y^I(t) = Y^I(t-1) * e^{\gamma^I(t)} \tag{57}$$

Import inflation is defined as:

$$\pi^I(t) = \alpha^{\pi,I}\gamma^I(t-1) + \beta^{\pi,I} + \epsilon^{\pi,I}(t-1) \tag{58}$$

And the price level is:

$$P_m(t) = P_m(t-1) * e^{\pi^I(t)} \tag{56}$$

Exporters

The growth rate of export demand follows an AR(1) process:

$$\gamma^E(t) = \alpha^{\gamma,E}\gamma^E(t-1) + \beta^{\gamma,E} + \epsilon^{\gamma,E}(t-1) \tag{60}$$

The demand for exports is thus determined by the formula:

$$C^E(t) = C^E(t-1) * e^{\gamma^E(t)} \tag{61}$$

Export price inflation is defined as:

$$\pi^E(t) = \alpha^{\pi,E}\pi^E(t-1) + \beta^{\pi,E} + \epsilon^{\pi,E}(t-1) \tag{62}$$

And the price level is:

$$P_E(t) = P_E(t-1) * e^{\pi^E(t)} \tag{63}$$

Aggregated macroeconomic variables

The aggregated variables in the model are calculated as the result of the actions of the individual agents in the economy. Thus, GDP can be calculated using three approaches, just as happens in real statistics. Calculating the aggregate indicators directly from the micro data is a big advantage of the AB approach and allows different levels of detail to be reconciled within one model.

Nominal GDP is calculated as:

$$\begin{aligned}
&\ddot{GDP}(t) = \\
&\underbrace{\sum_h \tau^{VAT} \ddot{C}_h(t) + \sum_j \tau^G \ddot{C}_j(t) + \sum_l \tau^{EXP} \ddot{C}_l(t)}_{Taxes\ on\ products} \\
&+ \underbrace{\sum_i P_i(t)\bar{\bar{Y}}_i(t)}_{\substack{Total\ sales\ of \\ good\ and\ services}} - \underbrace{\sum_i \frac{1}{\beta_i} P_i^{MAT} \bar{\bar{Y}}_i(t)}_{\substack{Intermediate \\ inputs}} \ (Production\ approach) \\
&= \underbrace{\sum_h (1+\tau^{VAT})\ddot{C}_h(t)}_{\substack{Household \\ consumption}} + \underbrace{\sum_j (1+\tau^G)\ddot{C}_j(t)}_{\substack{Government \\ consumption}} + \underbrace{\sum_i P_i^{CF}(t)\bar{\bar{I}}_i(t)}_{\substack{Gross\ fixed \\ capital\ formation}} \\
&+ \underbrace{\sum_i P_i(t)\left(\bar{\bar{Y}}_i(t) - \bar{\bar{Q}}_i(t)\right)}_{\substack{Change\ in\ finished \\ goods\ inventory}} + \underbrace{\sum_i P_i^{MAT}\left(\Delta\, \bar{\bar{M}}_i(t) - \frac{1}{\beta_i}\bar{\bar{Y}}_i(t)\right)}_{\substack{Change\ in\ inventories \\ of\ raw\ materials}} \\
&+ \sum_l \underbrace{(1+\tau^{EXP})\ddot{C}_l(t)}_{Exports} - \sum_m \underbrace{P_m(t)\bar{\bar{Q}}_m(t)}_{Imports} \ (Expenditure\ approach) \\
&= \underbrace{\sum_h \tau^{VAT} \ddot{C}_h(t) + \sum_j \tau^G \ddot{C}_j(t) + \sum_l \tau^{EXP} \ddot{C}_l(t)}_{Taxes\ on\ products} \\
&+ \sum_i \underbrace{\left(P_i(t)Y_i(t) - P^{HH}(t)N_i(t)\bar{\bar{w}}_i(t) - \frac{1}{\beta_i}P_i^{MAT}Y_i\right)}_{Gross\ operating\ surplus\ and\ mixed\ income} \\
&+ \sum_i \underbrace{P^{HH}(t)N_i(t)\bar{\bar{w}}_i(t)}_{\substack{Compensation \\ of\ employees}} \ (Income\ approach)
\end{aligned} \tag{57}$$

The GDP deflator is defined as the quotient of the nominal and real GDP for the period:

$$defl^{GDP}(t) = \frac{\ddot{GDP}(t)}{\overline{\overline{GDP}}(t)} \tag{58}$$

Real GDP is also calculated from the micro data of the agents in the model:

$$\begin{aligned}
&\overline{\overline{GDP}}(t) = \underbrace{\sum_h \tau^{VAT} \frac{\ddot{C}_h(t)}{P_h^{HH}(t)} + \sum_j \tau^G \frac{\ddot{C}_j(t)}{P_j^{JJ}(t)} + \sum_l \tau^{EXP} \frac{\ddot{C}_l(t)}{P_l^{LL}(t)}}_{Taxes\ on\ products} \\
&+ \underbrace{\sum_i \bar{\bar{Y}}_i(t)}_{\substack{Total \\ sales}} - \underbrace{\sum_i \frac{1}{\beta_i}\bar{\bar{Y}}_i(t)}_{\substack{Intermediate \\ inputs}} \ (Production\ approach) \\
&= \underbrace{\sum_h (1+\tau^{VAT}) \frac{\ddot{C}_h(t)}{P_h^{HH}(t)}}_{\substack{Household \\ consumption}} + \underbrace{\sum_j (1+\tau^G) \frac{\ddot{C}_j(t)}{P_j^{JJ}(t)}}_{\substack{Government \\ consumption}} + \underbrace{\sum_i \bar{\bar{I}}_i(t)}_{\substack{Gross\ fixed \\ capital\ formation}}
\end{aligned} \tag{59}$$

$$
+\underbrace{\sum_i \left(\bar{\bar{Y}}_i(t) - \bar{\bar{Q}}_i(t)\right)}_{\substack{Change\ in\ finished \\ goods\ inventory}} + \underbrace{\sum_i \left(\Delta\,\bar{\bar{M}}_i(t) - \frac{1}{\beta_i}\bar{\bar{Y}}_i(t)\right)}_{\substack{Change\ in\ inventories \\ of\ raw\ materials}}
$$

$$
+\underbrace{\sum_l (1+\tau^{EXP})\frac{\ddot{C}_l(t)}{P_l^{LL}(t)}}_{Exports} - \sum_m \underbrace{\bar{\bar{Q}}_m(t)}_{Imports} \quad (Expenditure\ approach)
$$

$$
= \underbrace{\sum_i \bar{\bar{Y}}_i(t) + \sum_h \tau^{VAT}\frac{\ddot{C}_h(t)}{P_h^{HH}(t)} + \sum_j \tau^G \frac{\ddot{C}_j(t)}{P_j^{JJ}(t)} + \sum_l \tau^{EXP}\frac{\ddot{C}_l(t)}{P_l^{LL}(t)}}_{Taxes\ on\ products}
$$

$$
+\sum_i \underbrace{\left(Y_i(t) - N_i(t)\bar{\bar{w}}_i(t) - \frac{1}{\beta_i}Y_i\right)}_{Gross\ operating\ surplus\ and\ mixed\ income}
$$

$$
+\sum_i \underbrace{N_i(t)\bar{\bar{w}}_i(t)}_{\substack{Compensation \\ of\ employees}} \quad (Income\ approach)
$$

Calibration

One of the advantages of using an agent-based approach is the ability to calibrate the model on a wide range of macroeconomic and, most importantly, microeconomic data. Taking such data into account allows the model to be 'tuned' to a specific economy and for consistent estimates to be obtained at three levels of detail at once: at the agent level, at the industry level, and at the macro level.

It is worth noting separately that in such a model, the variables are calibrated for each agent in the economy taking into account the available microdata and in such a way that when aggregating, the level of the resulting model macrovariables (such as, for example, GDP) corresponds to the level known to us from official statistics. Thus, this provides the opportunity to trace the contribution to GDP down to an individual agent. This level of detail, while maintaining consistency at the level of industries and the economy as a whole, is a great advantage of this class of models and provides ample opportunities for answering various research questions.

When calibrating, the period in the model is understood as a quarter. The starting point in the model is chosen to be 2021 Q1. The official statistics published by Rosstat are used for calibration. The following data are used: quarterly GDP (with breakdown by three approaches), input-output tables (translated in accordance with the keys of the Ministry of Economic Development from OKVED-2007 to OKVED-2), data on average monthly wages by industry (aggregated for the 3 months of the 1st quarter), and data on the number in the labour force and the employed and unemployed.

The growth rate of the real economy is calibrated at 0.5% per quarter (or 2% per year). The consensus on the medium-term potential growth of Russia's GDP is estimated at 1.5–2% (see, for example, the predictions of the IMF (2021), at 1.6%, and the World Bank (2021), at 1.8%).

The inflation growth rate π^* is calibrated at 1% per quarter (or 4% per year) based on the inflation target of the Bank of Russia (Bank of Russia, 2024).

The nominal neutral rate $\ddot{r}^*$ is calibrated as the sum of the inflation target π^* and the equilibrium real interest rate $\bar{\bar{r}}^*$. The equilibrium real rate is calibrated at 1.5% per annum. According to existing works, the real interest rate for the Russian economy until 2022 was probably in the range of 1 to 3%. For example, Kreptsev et al. (2016) calculate it at 1–3.2%, the IMF (2019) calculates 1–3%, and Isakov and Latypov (2019) calculate 1.5–2.5%. The Bank of Russia Monetary Policy Report (October 2022) talks about a range of 1–2% for the long-term real neutral interest rate.

Households

In the calibration of this sector, the concept of the 'household' is equivalent to the concept of an 'economic agent'. For calibration, data on the population of Russia over 15 years old are used. As discussed above, the households are divided into groups by labour force participation and by property ownership. Data on the employed and unemployed and the economically inactive population are used for the initial distribution of the households by work status.[7] For the initial distribution of the households by ownership status, it is assumed that each firm/bank can be owned by only one household. Thus, the number of households for which this status is not empty is 354+1=355.

As it is impossible to obtain actual statistics on the professions of the unemployed, I divide the unemployed by sector in the same proportions as the employed are divided. For example, sector 0 (A) employs about 1.6% of all the employed, and so the proportion of unemployed assigned to this sector is also 1.6% of the total.

Firms

The model contains 354 firms according to the statistics on the number of firms by OKVED-2 industries. The size of the economically active population in each industry is calibrated based on the number of employees by industry. Many empirical studies show an uneven distribution of firm size, so I use an exponential function to initially assign workers to firms in each industry (while keeping the total number of workers in each industry consistent with the statistics). The total number of unemployed is calibrated from the statistics. Given the lack of statistics on the number of unemployed in each industry, the unemployed are calibrated to particular industries in the same proportions as the number of employees in these industries to the total number of employees in the economy. As discussed earlier, this version of the model does not allow the industry of a firm or the occupation of a worker to change, and a worker can only be employed in a firm that matches his or her occupation.

Table **1** presents the calibration of the model parameters.

Table 1. Parameters

Parameter	Description	Value
ψ^H	share of income consumed	0.3596
θ	rate of debt repayment	0.05
θ^{UB}	portion of salary paid as unemployment benefits	0.55
θ^{DIV}	share of profits paid as dividends	0.9
ξ^b	share of inherited capital	0.5
ξ^{bank}	minimum capital requirement coefficient	0.03
ξ^{LTV}	loan-to-value (LTV) ratio	0.6
η	restrictions on hiring/firing	0.02
γ	‘equilibrium’ rate of economic growth	0.005
τ^{VAT}	value-added tax rate	0.1563
τ^{CF}	tax rate on capital formation	0.0086
τ^{EXP}	export tax rate	0.0464
τ^{IMP}	import tax rate	0.0173
τ^{MAT}	tax rate on intermediate goods	0.0364
τ^{G}	tax rate on government consumption	0.0004
π^{tar}	inflation target	0.01

Table **2** presents the model's sector-specific parameters. The sectors are designated using standard letter numbering.

Table 2. Industry parameters

	I_s	N_s	ω^{MAT}	α_g	β_g	κ_g	δ_g	b_g^{HH}	b_g^{CF}	b_g^{MAT}	b_g^{JJ}	b_g^{LL}	b_g^{MM}
A	10	449	0.9623	5.3774	1.5901	1433.7254	0.0510	0.0515	0.0003	0.0480	0.0015	0.0392	0.0413
B	2	116	0.9972	43.3902	2.0027	24.7940	0.0601	0.0002	0.0327	0.0685	0.0000	0.2475	0.0165
C	27	997	1.0000	18.0514	1.6008	9.5276	0.0641	0.3129	0.3047	0.6834	0.0051	0.4995	0.7845
D	2	158	0.9953	16.4835	1.2256	260439341	0.0369	0.0300	0.0000	0.0000	0.0071	0.0017	0.0004
E	2	71	1.0000	7.5885	1.3226	53878520	0.0341	0.0070	0.0000	0.0111	0.0018	0.0032	0.0033
F	40	650	1.0000	5.3542	4.8788	1.2620	0.0538	0.0003	0.4448	0.0412	0.0000	0.0137	0.0264
G	94	1324	0.9665	4.8163	2.7809	27.0045	0.1780	0.2224	0.0381	0.0835	0.0040	0.0626	0.0002
H	21	564	1.0000	8.6114	1.3146	213.5777	0.0186	0.0295	0.0037	0.0097	0.0224	0.0764	0.0224

[7] Real and model data are related at a scale of 1:10,000, i.e., the ≈121 million in the population of Russia over 15 years old corresponds to the ≈12,100 households of the model. This choice of scale is associated exclusively with the choice of adequate time for calculating the simulations for conducting the experiments.

I	9	182	1.0000	2.8150	5.0646	51232384	0.0318	0.0281	0.0000	0.0000	0.0012	0.0009	0.0003
J	11	156	1.0000	11.3477	1.5041	12.3682	0.0676	0.0286	0.0231	0.0052	0.0069	0.0208	0.0307
K	6	130	1.0000	16.3293	1.5348	212280424	0.1113	0.0543	0.0000	0.0000	0.0000	0.0049	0.0116
L	31	190	1.0000	22.3934	2.4591	23.9964	0.0021	0.1601	0.0286	0.0000	0.0145	0.0009	0.0014
M	30	273	0.9983	9.0449	1.6173	3.3493	0.0391	0.0034	0.1189	0.0492	0.0096	0.0223	0.0256
N	14	203	1.0000	6.2823	0.9852	46.9754	0.0741	0.0031	0.0044	0.0000	0.0124	0.0056	0.0337
O	9	364	0.9623	8.1554	54.2659	296856715	0.0002	0.0010	0.0000	0.0000	0.4889	0.0000	0.0000
P	13	532	0.9972	2.2388	23.9675	119102369	0.0001	0.0114	0.0000	0.0000	0.1655	0.0004	0.0009
Q	8	445	1.0000	3.7056	32.1665	164899065	0.0078	0.0283	0.0000	0.0000	0.2021	0.0001	0.0003
R	7	114	0.9953	3.6677	6.8112	98.8303	0.0046	0.0089	0.0007	0.0000	0.0387	0.0001	0.0005
S	17	158	1.0000	2.2046	3.9864	34832159	0.0113	0.0108	0.0000	0.0001	0.0182	0.0001	0.0001
T	1	154	1.0000	0.7521	11581683	11581683	0.0446	0.0082	0.0000	0.0000	0.0000	0.0000	0.0000

The decoding of the industry names is given in table Table *3*.

Table 3. Industries				
			Share of added value of industry in total (for 2021 Q1), %	**Industry workers to total number of employed (for 2021 Q1), %**
Ind_0	A	Agriculture, forestry & fishing	2.95	1.60
Ind_1	B	Mining & quarrying	8.30	13.79
Ind_2	C	Manufacturing	22.24	2.19
Ind_3	D	Energy supply services	1.58	0.98
Ind_4	E	Water and waste treatment	0.43	8.99
Ind_5	F	Construction	9.11	18.31
Ind_6	G	Wholesale & retail trade	13.45	7.80
Ind_7	H	Transport & storage	3.83	2.52
Ind_8	I	Accommodation & food	1.35	2.16
Ind_9	J	Information and communication	1.95	1.80
Ind_10	K	Finance & insurance	2.44	2.63
Ind_11	L	Real estate activities	8.31	3.78
Ind_12	M	Professional services	3.10	2.81
Ind_13	N	Administrative services	-0.06	5.03
Ind_14	O	Public sector & defence	9.59	7.36
Ind_15	P	Education	3.76	6.15
Ind_16	Q	Health & social care	5.26	1.58
Ind_17	R	Arts & recreation and other services	1.17	2.19
Ind_18	S	Provision of other types of services	0.86	2.13
Ind_19	T	Activities of households as employers	0.38	1.60

3. Labour market

As discussed in the introduction, there are several mechanisms in the labour market, supported by numerous theoretical and empirical studies, that are critical to understanding the processes occurring in this market. This section discusses how these mechanisms are integrated into the baseline model and the calibration of their parameters.

Since the experiments consider both the baseline model with and without shocks and a complex labour market model with and without shocks, as well as various training programmes, for brevity and to avoid confusion, here and below, the baseline model is referred to as the 'Industries' scenario, and the complex labour market model is referred to as the 'Skills' scenario.

3.1. Labour mobility

The model includes two possible scenarios for labour force mobility.

The 'Industry' scenario assumes that each household in the labour force belongs to a specific industry, and this industry remains constant throughout the simulation period. A household can work only for firms that correspond to its industry. Consequently, employee mobility between firms is significantly limited.

The 'Skills' scenario assumes that each employee possesses a specific set of skills. These skills are initially determined by their industry (occupation) but can change during the simulation. In this version, an unemployed household can be employed not only by a firm that corresponds to its industry, but also by a firm in another industry if its current skills are sufficient for that industry.

To calibrate skills by industry, I use data from household surveys in EU countries on the skills required in the corresponding industries. Unfortunately, there is no similar survey for Russia. However, this is a large-scale survey conducted across 27 European Union countries. The industries represented in the survey, with one exception, fully correspond to the OKVED-2 classification, and the skills are defined quite generally. Given this, it is highly likely that a similar ratio of industries and skills will be found in Russia.

The survey includes 21 skills, each assigned a numerical value from 0 to 100 representing the percentage of respondents who answered the question a certain way, such as respondents who answered the question 'How often have you performed any of the following activities as part of your main job during the past month?' with 'Always or very often'.

The data by industry and skills are summarised in table **4**. The horizontal axis represents 20 macro-industries according to the letter codes of the Russian Classifier of Types of Economic Activity (OKVED-2), and the vertical axis represents the corresponding skills. A breakdown of the industry letter codes is presented in table **3**.

Table 4. Industries-skills. Orange indicates the highest skill. Blue indicates the lowest skill for each skill.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S/T
Use of digital device for work	71	68	81	94	81	84	86	86	68	99	99	95	98	85	95	92	89	88	81
Digital activities at work	15	12	12	13	15	11	11	10	9	42	15	13	15	11	11	9	7	11	16
Providing advice or counselling	13	18	15	20	17	14	36	18	22	25	35	32	25	25	29	31	40	26	31
Giving presentations	9	7	9	10	7	8	20	8	15	16	19	15	12	11	8	15	10	13	19
Dealing with outsiders	16	12	16	25	17	20	49	30	38	28	34	41	26	29	28	22	37	37	39
Teaching or training	10	3	7	6	5	6	9	6	9	8	5	8	9	6	7	41	10	11	10
Caring for others	10	7	6	11	5	6	8	5	11	6	7	12	8	8	11	27	38	14	18
Selling	8	6	7	7	3	4	19	6	12	8	15	10	8	9	5	11	10	10	11
Teamwork	24	51	34	38	22	31	35	27	35	40	34	28	31	29	32	33	43	35	29
Working on varying tasks	23	29	26	28	20	26	22	21	25	26	28	28	29	24	29	25	27	28	33
Learning new things	18	16	19	23	14	17	16	16	20	25	23	16	23	18	18	31	22	23	26
Change in time spent learning new things	16	20	19	20	14	17	16	17	19	22	24	21	24	19	20	29	21	23	25
Reading tasks	13	21	17	23	24	18	12	15	9	32	36	24	38	21	35	35	16	27	22
Writing tasks	5	6	7	9	10	9	4	5	5	16	12	7	19	8	13	16	6	11	7
Lifting heavy loads	48	44	40	29	38	51	49	42	56	14	6	11	16	25	20	21	44	36	31
Hazardous work	46	52	40	36	44	40	26	31	42	11	7	13	17	20	18	15	27	25	28
Use of digital machines at work	41	44	54	40	32	38	53	46	38	32	32	25	34	31	25	30	29	34	27
Mathematical tasks	17	12	17	19	21	20	13	12	10	23	26	21	26	13	13	18	7	9	10
Developing or creating new products or services	10	7	9	8	6	8	8	5	10	16	9	5	11	6	6	10	7	8	11
Developing new work methods	11	14	11	11	8	10	10	9	11	15	11	8	13	9	9	16	12	11	17
Trying out new ideas	8	10	9	8	7	9	9	7	10	13	8	10	13	10	8	17	12	11	15

In the data, the last industry is called 'Non-market services', while this roughly corresponds to two industries in OKVED-2: S 'Provision of other types of services' and T 'Activities of households as employers; undifferentiated activities of private households in the production of goods and provision of services for own consumption'. For simplicity, I assume that the skills for industries S and T are identical. The remaining industries are fully correlated in the European and Russian classifications.

As table **4** shows, the most skill-demanding sector is sector P (Education). It requires the highest scores in 4 of 21 skills. Sectors G (Wholesale and Retail Trade), J (Information and Communications), and M (Professional, Scientific, and Technical Activities) are also highly skill-demanding. The least demanding sector is sector E (Water Supply), requiring the lowest scores in 9 of 21 skills among all sectors.

First, it is worth noting that if the condition for an employee to move from one industry to another is the possession of all skills equal to or greater than those in the new industry, then the 'Industry' and 'Skills' versions are completely identical, since no pair of industries can fully satisfy the needs of the other. Therefore, when conducting the experiments, I consider several scenarios in which the partial satisfaction of industry skills requirements is sufficient for a transition from one industry to another.

For clarity, table **5** presents matrices for various admissible calibrations of transitions between industries. The parameter o ∈ [0,1] determines for what percentage of the skills (out of 21) the condition 'greater than or equal' between the values of the old and new industries must be satisfied. That is, o=1 means that all skills must be no lower than in the new industry, and o=0.3 means that this condition must be satisfied only for 6 skills out of the 21 ([0.3*21]=6). For the matrices presented below, a value of 0 or 1 determines the possibility of moving from one industry to another. For example, if the element (A,B) = 1, this means that a worker can move from industry B to industry A (the converse is true only if (B,A) = 1).

Table 5. Matrices of possibility of workers moving from one industry to another depending on parameter o

o=1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S/T
A	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
H	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Q	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
S/T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

o=0.7

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S/T
A	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0	1	1	1	1
B	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1
C	0	0	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1
D	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0	1	0
E	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
F	0	0	1	1	0	1	0	0	1	1	1	0	1	0	0	1	0	1	0
G	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
H	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
I	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1
J	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	0	1	1
M	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
N	0	0	0	1	0	0	1	0	1	1	1	0	1	1	0	1	1	1	1
O	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	1	1	1
P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Q	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
S/T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

o=0.5

o=0.3

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S/T
A	1	0	1	1	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1
B	1	1	1	1	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1
C	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	1	1	1	1
D	0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	1	1	1	1
E	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F	0	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1
G	1	0	1	1	0	1	1	0	1	1	0	0	1	0	0	1	1	1	1
H	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
I	0	1	0	1	0	0	1	0	1	1	1	1	1	0	0	1	1	1	1
J	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	1	0	0	1
K	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	0	0	1	1
L	0	0	0	0	0	0	1	0	1	1	1	1	1	0	1	1	1	1	1
M	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	1
N	0	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1
O	1	1	1	1	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1
P	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
Q	0	1	0	1	0	0	0	0	0	1	1	0	1	0	0	1	1	1	1
R	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1	0	1	1
S/T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S/T
A	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
D	1	1	1	1	0	1	1	0	1	1	1	1	1	0	1	1	1	1	1
E	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
G	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1
H	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
I	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1
J	0	0	0	0	0	0	1	0	1	1	1	1	1	0	1	1	1	1	1
K	1	1	1	1	0	0	1	0	1	1	1	1	1	0	1	1	1	1	1
L	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
M	1	0	0	0	0	0	1	0	1	1	1	0	1	0	1	1	1	1	1
N	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
O	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P	0	0	0	1	0	0	1	0	1	1	1	1	1	0	0	1	1	1	1
Q	1	1	1	1	0	1	1	0	1	1	1	1	1	0	0	1	1	1	1
R	1	1	1	1	0	0	1	0	1	1	1	1	1	0	1	1	1	1	1
S/T	0	0	1	1	1	1	1	0	0	1	1	0	1	0	0	1	1	1	1

Based on labour force survey data on the educational attainment and occupations of all employed workers in more than 130 countries, the International Labour Organization has calculated that only about half of the employed hold jobs commensurate with their educational attainment. The rest are either over- or under-educated for their jobs.[8]

Several surveys across Russia show similar results. The SuperJob survey (2024)[9] conducted among 3,500 respondents with higher education shows that only 46% of them are working in their fields of study. This means that more than half (54%) are working outside their fields of study or in related fields. The Avito Jobs survey (2024)[10] conducted among 7,000 employed Russians shows that approximately 50% of them are pursuing careers outside the fields they studied at their universities or vocational schools.

Based on this, I choose o = 0.55 for the baseline calibration, which allows for the transition to occur for approximately half of the industries. **Section 5** analyses the sensitivity of the results to this parameter.

3.2. Depreciation of skills of unemployed

Although, as noted in the introduction, there are a number of studies discussing skill loss during unemployment, their quantitative estimates focus on the relationship between the duration of unemployment, post-employment wages, and the job-finding difficulty faced by the unemployed, implicitly assuming that skill loss is the cause of this relationship. Much of the uncertainty in this area likely stems from the fact that skills (unlike wages or the number of quarters an individual remains unemployed) are unobservable. Both the definition of 'skill' and the methods for measuring it leave ample room for interpretation. I capture skill loss among the unemployed in the model using a simple rule that the *o*-th skill of the *h*-th worker decreases by a fixed percentage *amort* of their corresponding skill in the previous period for each period of unemployment:

$$skill_h^o(t) = (1 - amort) * skill_h^o(t-1)$$

Regarding calibration, the relevant literature (e.g., the work of Jackson and Ortego-Marti (2024)) typically uses a numerical estimate of wage changes as a benchmark for skill depreciation, and I also follow this logic. Furthermore, as follows from equation (7) (see the **Labour Market → Wages** section), the structure of my model implies a skill-dependent wage, which links wages, skills, and the chosen calibration.

[8] https://ilostat.ilo.org/only-half-of-workers-worldwide-hold-jobs-corresponding-to-their-level-of-education/

[9] https://www.superjob.ru/research/articles/114658/rabotat-po-specialnosti/

[10] https://www.avito.ru/company/press/avito_rabota_31_procent_rossiyan_rabotayut_po_specialnosti_poluchennoj_v_vuze_ili_ssuze

Ortego-Marti (2016), using data from a large cohort of US workers, documents that an additional month of unemployment is associated with a 1.22% wage loss. Schmieder et al. (2016) obtain an estimate of 0.8% monthly wage loss using German data. Addison and Portugal (1989) find a monthly wage loss of 1.44%. Neal's (1995) estimate using US data indicates a monthly depreciation of 1.59%. Given these studies and the quarterly basis of the model, I choose a skill depreciation parameter of *amort*=0.0375, which corresponds to a depreciation of 1.25% per month or 15% per year.

3.3. Adaptation and learning-by-doing

As noted in the introduction, adaptation and learning, as well as the phenomenon of skill 'depreciation' and 'recovery', are important components of the labour market. I incorporate this mechanism into my model as follows. For all households employed in the current period, the following revaluation of skills occurs at stage four of the model. Those worker skills that are higher than the skills of the firm where they work (i.e., for the *o*-th skill, $skill_h^o(t) > skill_i^o$) are reduced by the difference between the firm's skills and the worker's skills, but not by more than a certain amount ε:

$$skill_h^o = skill_h^o + max(-\varepsilon * skill_h^o, skill_i^o - skill_h^o), \tag{60}$$

and the worker's skills which are lower than the firm's skills (i.e., for the *o*-th skill, $skill_h^o(t) < skill_i^o$) are increased by the difference in the worker's skills, but not by more than the same amount ε:

$$skill_h^o = skill_h^o + min(\varepsilon * skill_h^o, skill_i^o - skill_h^o). \tag{61}$$

If the worker returns to the same industry where they worked before being laid off, equation (60) will never hold, and equation (61) will reflect the recovery of skills upon returning to work. If the worker switches industries, equations (60) and (61) together will reflect the adaptation process and the learning-by-doing process.

As mentioned in the introduction, I am unaware of any studies that directly assess skill changes during industry switches. Studies discussing the onboarding process for new employees (Bauer and Erdogan, 2011; van Dam, 2009) generally agree that the onboarding process takes between three months and a year. Given that my work focuses on onboarding after unemployment and occupational switching, I choose a one-year onboarding period (i.e., $\varepsilon = 0.25$) as the benchmark for the baseline calibration.

3.4. Wages

The ‘Skills’ scenario includes three wage-related additions.

First, wages are linked to employee skills. Employees returning to work after a period of unemployment and employees who switch industries receive lower wages than other employees until their skills fully match those required by the firm, consistent with the empirical and theoretical research on this topic.

Second, unemployment benefits decline proportionally to the rate of skill loss. Thus, equation (3) becomes:

$$\ddot{w}_h^e(t) = \begin{cases} \overline{\overline{w}}_i(t) * \chi^H(t) * P^{HH}(t-1) * \left(1+\pi^e(t)\right), \text{if } hh \text{ works in firm } i \\ \ddot{w}_h(t-1) * amort * \left(1+\pi^e(t)\right), \text{WS} = \text{U} \end{cases} \tag{3'}$$

where P^{HH} is the CPI and $\chi^H(t)$ is a coefficient reflecting the concordance of the employee’s qualifications with the company where he or she is employed. $\chi^H(t)$ is determined by the formula:

$$\chi^H(t) = \frac{\sum_{i=1}^{21} pp_i}{21}, pp_i = \begin{cases} 1, if\ skill_h \geq skill_i \\ 0, otherwise \end{cases}$$

and equation (7):

$$\ddot{w}_h(t) = \begin{cases} \overline{\overline{w}}_i * \chi^H(t) * P^{HH}(t), \text{if } hh \text{ works in firm } i \\ \ddot{w}_h(t-1) * amort * \dfrac{P^{HH}(t)}{P^{HH}(t-1)}, \text{WS} = \text{U} \end{cases} \tag{7'}$$

Third, workers have certain power in the labour market. They will not accept offers from firms whose wages are lower than their unemployment benefits.

4. Experiments

In this section, I test the hypotheses formulated in the introduction using simulations based on the model constructed.

First, I test the existence of unemployment scars for GDP, that is, a significant difference between the GDP trajectories with and without a shock which persist even after the shock has passed for the model with the complex labour market. I assume that this difference is linked specifically to the labour market, so no such difference will be observed in the 'Industries' scenario.

Second, I hypothesise that job training programmes for the unemployed can help mitigate this difference. I examine the impact of two types of programmes: a general programme targeting all industries and a more targeted programme aimed at stimulating specific industries.

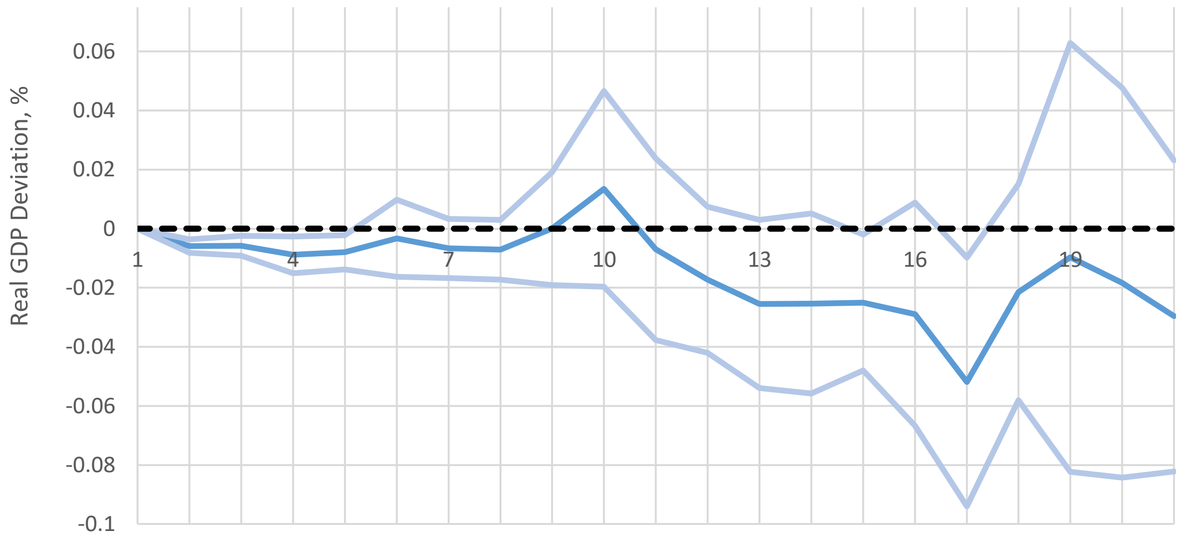
Third, I hypothesise that different industries respond differently to the aggregate shock. Such differences in industry responses may be related to the labour structure required by each industry.

An aggregate supply shock is chosen for the experiments. This shock is chosen because the initial impulse is the same for all industries, allowing for further conclusions to be drawn about the shock's impact on different industries.

4.1. No shocks

As a starting point, I analyse the differences between the 'Skills' and 'Industries' scenarios in the absence of a shock (and, consequently, significant changes in the labour market). As figure **1** shows, there is no statistically significant difference between these scenarios. Thus, in the absence of shocks, the impact of labour market difficulties on GDP appears insignificant. However, when a shock occurs, the situation changes dramatically.

Figure 1. Deviation of GDP in 'Skills' scenario from 'Industries' scenario in absence of shocks, %, average of 100 simulations, 95% confidence interval

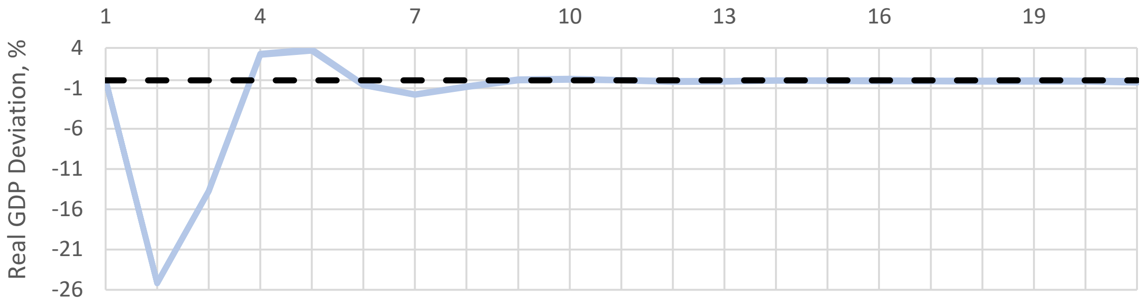


4.2. Aggregate supply shock

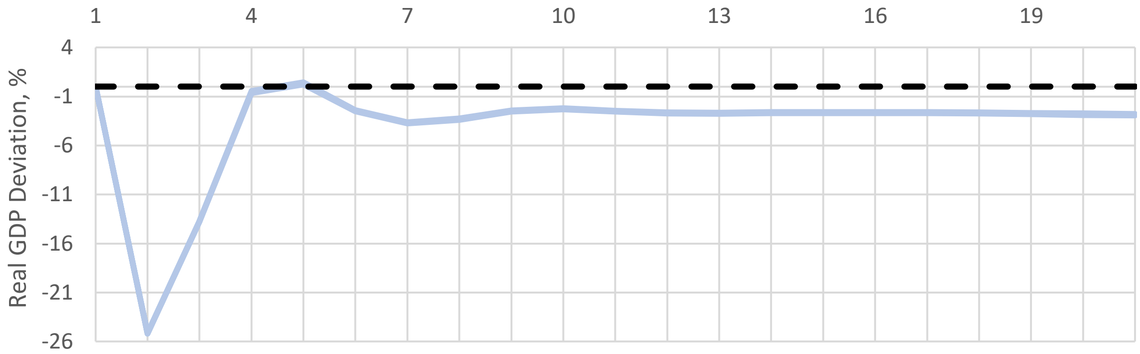
When a 25% aggregate supply shock occurs in the first period of the simulations, changes occur in the labour market that, in the 'Skills' scenario, have at least a medium-term impact on GDP. As figure **2** (b) shows, GDP remains approximately 3% lower 20 quarters after the shock in the 'Skills' scenario with a shock compared to the 'Skills' scenario in which such a shock does not occur. However, figure **2** (a) shows that this situation is not observed for the 'Industries' scenario: the shock quickly fades, and by the 10th period, the difference between the situation with and without the shock for this scenario is close to zero.

Figure 2. Deviation of real GDP in model with 25% supply shock in zero period from model without shock, %, average of 100 simulations, 95% confidence interval

(a) ‘Industries’ baseline scenario



(b) ‘Skills’ scenario with difficult labour market



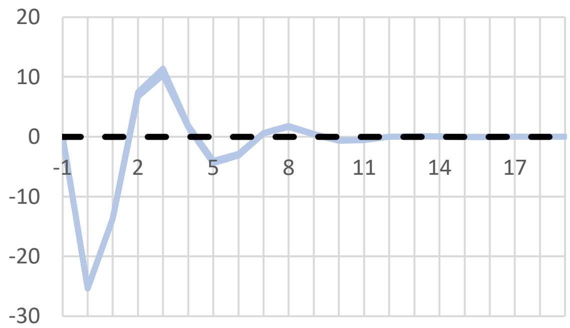
I will now discuss in more detail the reasons for the emergence of this impact of the shock for the ‘Skills’ scenario in the sectoral context and the possibilities of overcoming the medium-term consequences with the help of government programmes.

4.3. Analysis by industry

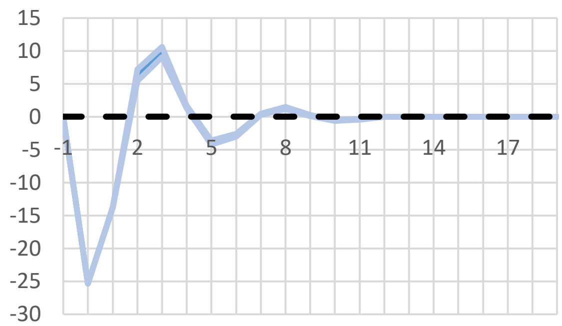
A more detailed analysis shows that this aggregate shock affects different industries differently. Certain industries in the ‘Skills’ scenario fully recover from the shock, and there is no significant difference between the two scenarios over the medium term. figure **3** shows an example of such industries.

Figure 3. ‘Skills’ scenario. Industries that fully recover from shock. Deviation of GDP in model with 25% supply shock in zero period from model without shock, %, average of 100 simulations, 95% confidence interval.

(a) B (Mining)



(b) E (Water supply)

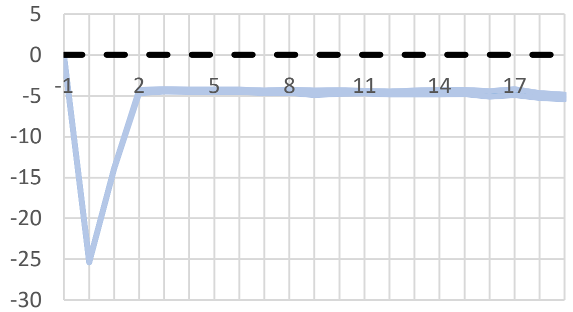


For other sectors, the impact of a single-period shock in the ‘Skills’ scenario, on the other hand, is very significant over the medium term. As figure **4** shows, the most significant impacts are observed in sectors I (Hotel and Catering Services), L (Real Estate Services), M (Professional, Scientific, and Technical

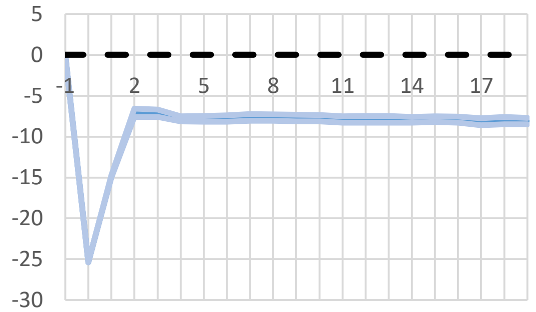
Services), and S (Provision of Other Services). The shock also has a significant impact on sectors R (Culture, Sports, Leisure, and Entertainment Services) and N (Administrative and Related Services).

Figure 4. 'Skills' scenario. Industries most susceptible to shock. Deviation of GDP in model with 25% supply shock in zero period from model without shock, %, 95% confidence interval.

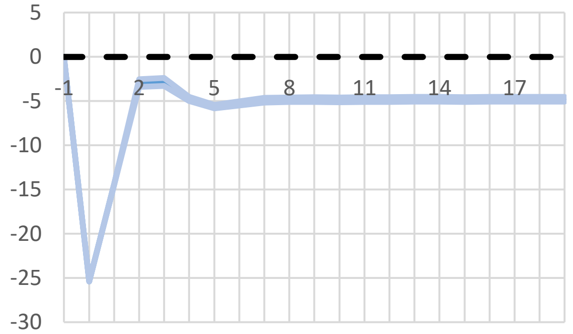
(a) I (Hotel and Catering Services)



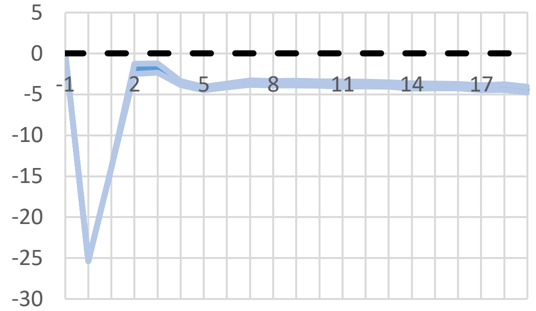
(b) L (Real Estate Services)



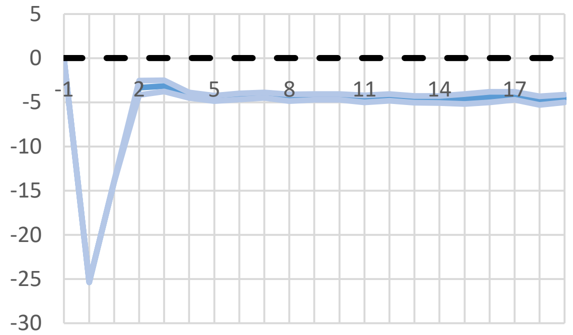
(c) M (Professional, Scientific and Technical Services)



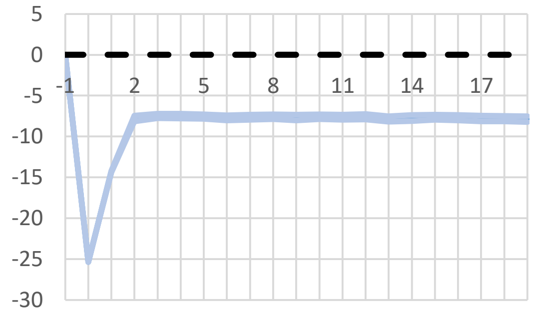
(d) N (Administrative and Related Services)



(e) R (Culture, Sports, Leisure, and Entertainment Services)



(f) S (Provision of Other Services)



Why do such differences exist across industries? To my knowledge, no studies discuss this issue. However, there are a number of studies that examine the determinants of unemployment scars from the perspective of workers, and their findings can be used to formulate the hypotheses in this paper. First, many studies (see, e.g., the work of Acemoglu (1995), Dieckhoff and Giesecke (2024), and Shi et al. (2018)) identify the determinants of unemployment scars as the match between a potential worker and the job (i.e., their skill level) and the duration of unemployment (which can essentially be interpreted as the loss of skills during unemployment, with the longer a person remains unemployed, the greater the loss of skills). From a firm's perspective, this means that the higher the skills required in a given industry, the more difficult it is to find suitable workers and, likely, the greater the scars following a shock for that industry. Secondly, as is well known, wages are a key factor in employer choice, so firms with higher wages (all other things being equal) will likely find it easier to find workers, and the impact of the shock on them will be milder. Thus, the degree of impact of the shock on industries in different scenarios likely depends on the relative ease or difficulty of hiring workers in a given industry.

To formalise these considerations for my model, I estimate a cross-sectional regression using the deviation of GDP in the shock scenario from the no-shock scenario 20 quarters after the shock as the explanatory variable (i.e., the medium-term impact of the shock on value added). The covariates are industry skills, the average industry wage, the initial calibration for the quantity of intermediate goods and capital required in the industry (as a proxy for the industry's dependence on other industries), and the ratio of the number of industry workers to the number of firms in the industry (as a proxy for the share of output produced by each worker).

Instead of including the 21 skill variables in the model, I use a skills index. This is motivated, first, by a reluctance to estimate a large number of coefficients on a limited number of observations, and second, by the high probability that skills are correlated, such as ‘Using digital devices at work’ and ‘Digital activities at work’ or ‘Developing or creating new products or services’ and ‘Developing new work methods’. I construct the index reflecting industry skill as follows: industry *g* is assigned a score of 1 for skill *s* if its skill *s* is greater than or equal to the median value for this skill across all industries, and 0 otherwise, and then the resulting scores are summed.

Although the limited number of observations should be taken into account when interpreting the results, the coefficient estimates obtained may describe the reasons for the differences in the responses of different industries to the aggregate shock. The results of the least squares estimation are presented in table **6**. As can be seen, skill and the ratio of the number of workers in the industry to the number of firms in the industry have a statistically significant effect on the magnitude of the shock's impact on value added, while the other variables are statistically insignificant. Furthermore, the results of the empirical analysis are consistent with the theoretically expected signs of the coefficients: the greater the skill, the more difficult it is for a firm to find workers and the greater (in absolute value) the impact of the shock; the higher the average number of workers in a firm, the lower the output per worker and the lesser the impact of the difficulty of hiring workers on output.

Table 6. OLS estimate of determinants of response of different industries to supply shock (in terms of loss of value added)

	Coefficients	*Standard error*	t- *statistics*	P-*Value*
Constant	-1.36	1.51	-0.90	0.38
Skills	-0.30***	0.12	-2.56	0.02
Wages	0.57	0.59	0.97	0.35
Intermediate goods	0.05	0.05	0.85	0.41
Capital	-0.05	0.04	-1.34	0.20
Ratio	0.03**	0.01	2.82	0.01

** – significant at the 0.05 level, ***– significant at the 0.01 level

Table **7** re-estimates the regression for the regressors found to be significant. As the table shows, the estimated coefficients remain virtually unchanged, supporting the robustness of the estimates obtained.

Table 7. OLS estimate of determinants of response of different industries to supply shock (in terms of loss of value added)

	Coefficients	*Standard error*	t- *statistics*	P-*Value*
Constant	-1.47	1.02	-1.44	0.17
Skills	-0.31***	0.09	-3.38	0.00
Ratio	0.04***	0.01	3.20	0.01

*** – significant at the 0.01 level

4.4. Training programmes for unemployed

As noted in the introduction, governments around the world are actively attempting to mitigate the effects of unemployment. How extensive should such programmes be to offset the impact on GDP?

I begin my analysis with a programme that applies to the unemployed, regardless of sector. This is a training programme for the unemployed that improves the skills of a randomly selected group of the unemployed (a share of the total unemployed, gp_{coef1}). The skills of the selected unemployed are increased by gp_{coef2} percentage points. gp_{coef3} controls the percentage of skills that are increased.

Clearly, the higher each coefficient, the greater the share of available highly skilled workers in the economy and the easier it is for firms to hire workers and overcome the effects of the crisis.

The question arises as to what values of these coefficients will be sufficient to overcome the effects of the crisis. As the results show (figure **5**), the following calibration allows this to be achieved: $gp_{coef1} = 0.5$, $gp_{coef2} = 1.1$, $gp_{coef3} = 0.5$.

Figure 5. Deviation of GDP in 'Skills' scenario and in 'Training for unemployed' scenario from scenario with 25% supply shock in 0-period, %, average of 100 simulations, 95% confidence interval.

4.5. Targeted programmes for students

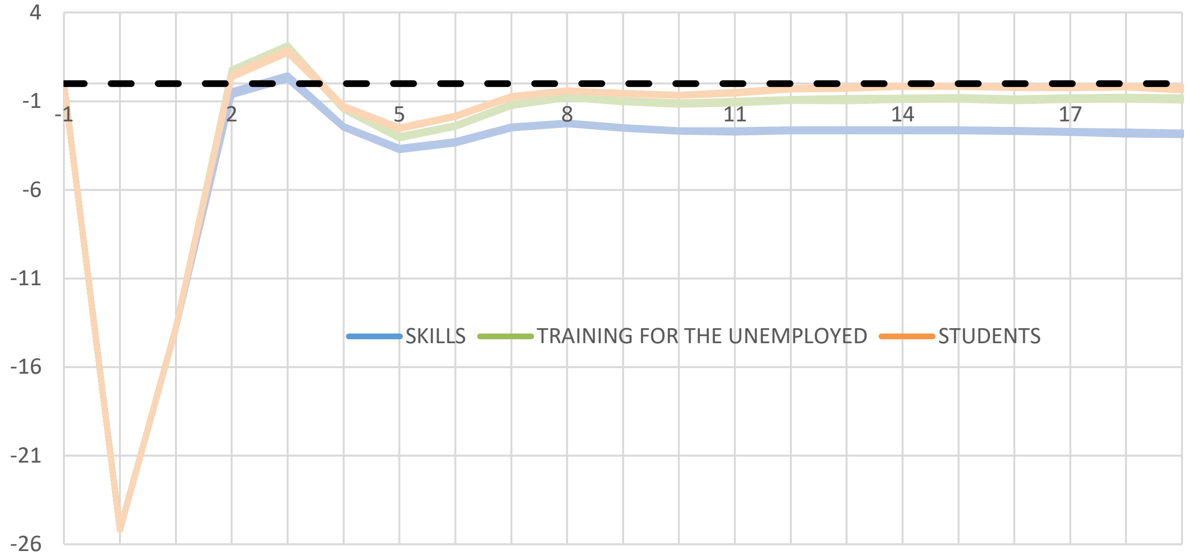
The analysis above suggests the possibility of using industry-specific training programmes (affecting a smaller number of agents) to achieve comparable results for several reasons. First, as has been established, the medium-term effects of a shock vary across industries, with those requiring higher skill levels being the most affected. Second, as noted in the introduction, there are a number of studies confirming the effectiveness of industry-specific training programmes, including for aggregate variables.

Suppose there are targeted training programmes for students in a given industry. It is assumed that an agent from the economically inactive category (a student) enters the labour market (as unemployed) with skills appropriate to the industry selected, and firms in this industry initially (during the period when the agent enters the labour market) receive priority in hiring this agent. Simultaneously, a randomly selected agent from the unemployed category becomes economically inactive (retires). This latter approach is intended to avoid the additional positive effect of an increase in the total number of economically active workers.

Using this scenario, I attempt to provide targeted support to several of the hardest-hit industries. The natural candidates are the hardest-hit industries with high skill requirements: 8, 11, 12, and 18. Of these industries, I include industry 12 in the experiment because it has the highest skills of all, and a skills-enhancing training programme may be most effective for it. Second, I include industry 11 because it is the hardest-hit of all the industries. The scenario includes training for students in these industries. The number of students trained is selected from the unemployed as a share of the industry's workforce relative to the total number of employed. That is, table 3 makes it clear that this represents ≈ 4% of the unemployed for industry 11 and ≈3% of the unemployed for industry 12.

As can be seen in figure **6**, training only 7% of the unemployed (4% for industry 11 and 3% for industry 12) has a comparable effect to training a significantly larger number of casual unemployed in casual skills.

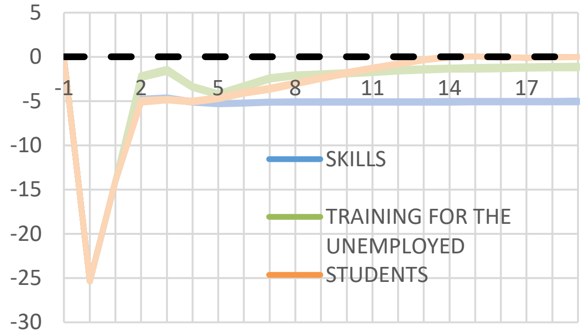
Figure 6. Deviation of GDP in ‘Skills’, ‘Training for unemployed’ and ‘Students’ scenarios with 25% supply shock from scenarios without shocks, %, average of 100 simulations, 95% confidence interval.



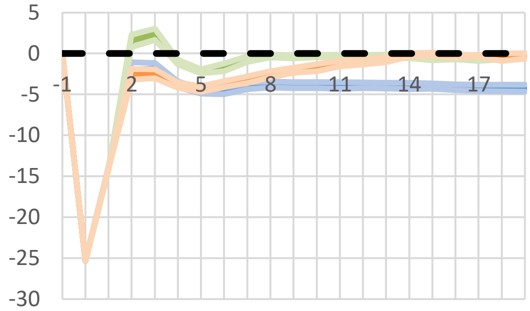
As can be seen in figure 7, the ‘Students’ programme leads to a full recovery in industries 11 and 12. However, this is not observed for industry 18. Nevertheless, this is sufficient to achieve the same effect on aggregate GDP as the ‘Training for unemployed’ programme.

Figure 7. Industries most affected by supply shock: three scenarios.

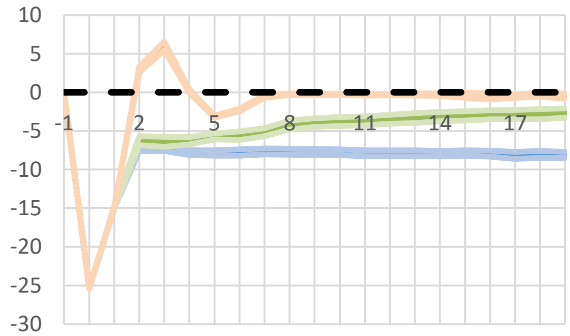
(a) Ind_6



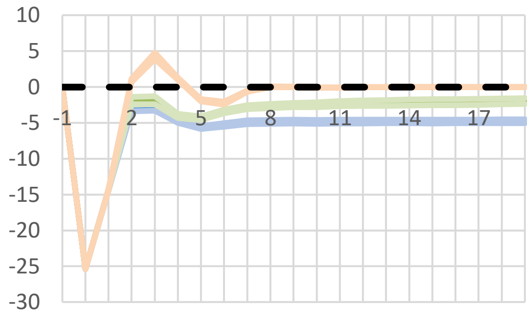
(b) Ind 9



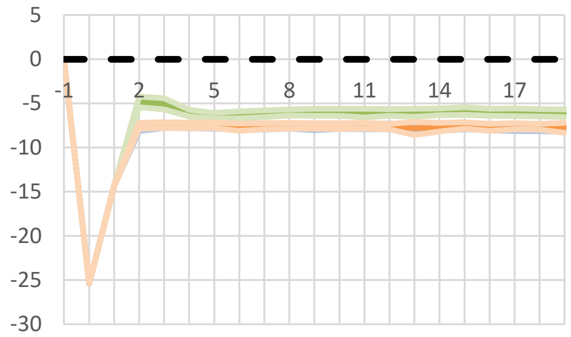
(c) Ind 11



(d) Ind 12



(e) Ind 18



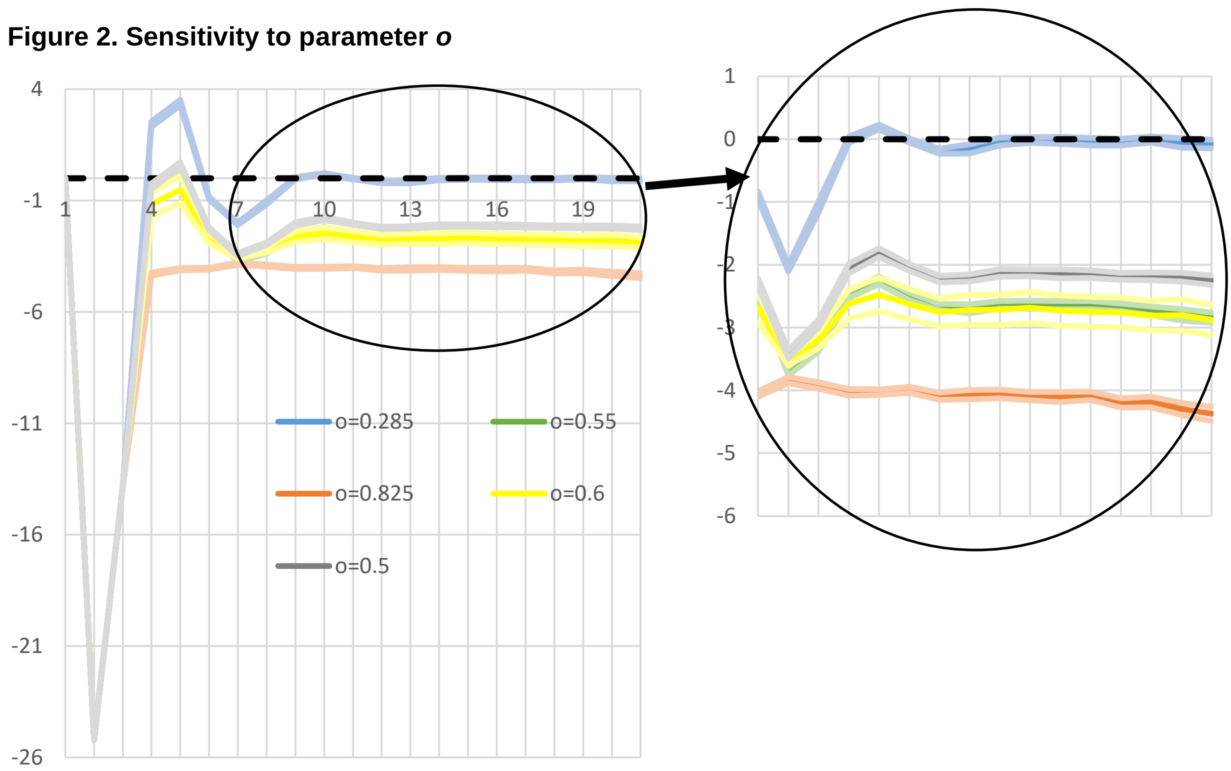
5. Robustness testing and sensitivity analysis of coefficients

Although most of the model parameters are calibrated using micro- and macro-data for Russia, a number of parameters which are not available in the data are selected based on estimates obtained in other studies. Further complications arise from the fact that certain estimates are not available for Russia, necessitating the use of estimates for other countries. While there is no reason to believe that processes such as worker adaptation or skill loss during unemployment, or their parameters, should differ significantly for Russia compared to other countries, this raises the question of the robustness of the results described in Section 4 to the choice of these parameters. This section discusses a series of experiments demonstrating the impact of key labour market parameters not directly calibrated from the data on the simulation results.

5.1. Sensitivity to parameter *o*

One of the key parameters responsible for labour market processes is parameter *o*, which characterises the proportion of a potential employee's skills that must match those required by the employer in order to be hired. In other words, this parameter reflects the employer's concern for the applicant's skills and ranges from 0 (complete unconcern; any candidate will be hired) to 1 (complete concern; only a candidate who fully meets the required skills will be hired). As discussed earlier, based on International Labour Organization estimates and surveys in Russia, this parameter is 0.55 in the basic calibration, which corresponds to approximately half of the workers transitioning between industries. How does changing this parameter affect the results?

Figure 2. Sensitivity to parameter *o*



As can be seen in Figure **2**, increasing parameter *o* by approximately 10% (to *o* = 0.6) only slightly reduces GDP and has no statistically significant effect on the results. The effect is more pronounced for a small decrease in *o* (to *o* = 0.5): this leads to an improvement in the GDP trajectory of approximately 0.5 percentage points. Although this effect is statistically significant, it does not materially affect the model's conclusions.

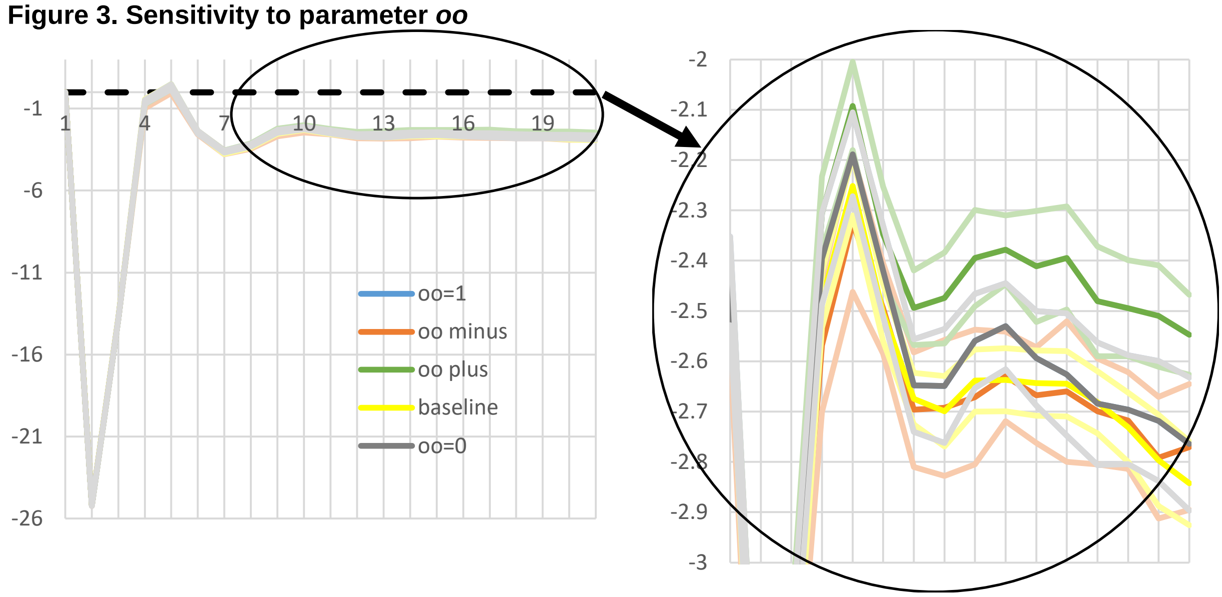
Meanwhile, a significant decrease in *o* (by a factor of 1.5, to *o* = 0.285) leads to the complete recovery of GDP after the shock. Thus, the 'Industries' and 'Skills; scenarios do not differ significantly in this case. In other words, in this case, labour market difficulties have no effect on GDP at all.

It is also interesting to note that changing parameter *o* has an asymmetric effect on the results. As can be seen, increasing *o* by a factor of 1.5 (to *o* = 0.825) leads to a final decrease in GDP of only 4%, meaning the response to an increase in *o* is three times weaker than the response to a decrease in *o*.

5.2. Sensitivity to parameter *oo*

Another important labour market parameter is parameter *oo*, which characterises the number of periods it takes for a new employee to fully adapt to the firm's skills – that is, to lose skills which are superior to those at the firm and to acquire those which are inferior. As discussed earlier, the adaptation process typically takes from one quarter (*oo* = 1) to a year (*oo* = 0.25). Since this study focuses on industry switching and re-employment after unemployment, a maximum adaptation period of one year is chosen as the baseline calibration. What does changing this parameter lead to?

Figure 3. Sensitivity to parameter *oo*



As **Figure 3** shows, both increasing parameter oo to 1 and decreasing it to 0 have an insignificant effect on the GDP trajectory. This is likely at least partly due to the fact that adaptation essentially consists of two opposing processes: certain skills are lost (reducing the GDP trajectory), while others are acquired (increasing the GDP trajectory).

To separate these effects, for the basic calibration, I run additional simulations of *oo minus* (skills are only lost) and *oo plus* (skills are only acquired). As **Figure 3** shows, the *oo minus* scenario does not differ significantly from the baseline trajectory, while the *oo plus* scenario demonstrates significant differences. This suggests that the effect of skill loss outweighs the effect of skill acquisition.

5.3. Sensitivity to parameter *amort*

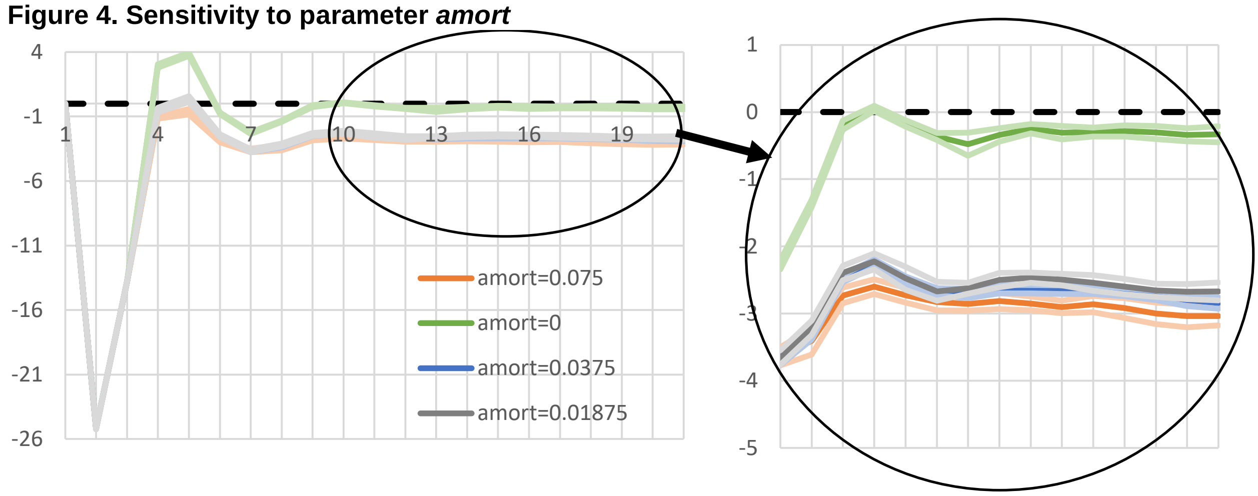
Another important parameter determining labour market processes is the amortisation parameter, which determines the percentage of skills depreciated among the unemployed. In the baseline calibration, this parameter is equal to 3.75% per quarter (equivalent to 15% per year).

The results of a sensitivity analysis for the *amort* parameter (**Figure 4**) show that the model's results are quite robust to changes in this parameter. Halving the parameter (to 0.01875) leads to a statistically insignificant improvement in GDP compared to the baseline trajectory. Doubling this parameter leads to a statistically insignificant deterioration in the GDP trajectory.

Meanwhile, the very inclusion of the possibility of skill loss during unemployment in the model significantly influences the medium-term consequences for GDP: in the baseline calibration (*amort*=0.0375), the deviation of GDP from the model without a complex labour market is ≈3%, while with *amort*=0, it is only ≈0.6% by the 20th quarter.

It is also worth noting that this 0.6% arises from the adjustment mechanism: the acquisition or loss of skills to align worker skills with firm skills. Although the previous point demonstrates a weak response of the GDP trajectory to changes in this parameter, this is likely due to the 'noisiness' of the adjustment effect by the stronger depreciation effect. In the absence of depreciation, the effects of adjustment have a more substantial and significant impact on GDP.

Figure 4. Sensitivity to parameter *amort*



Thus, a sensitivity analysis of the parameters shows that the models are quite robust to minor adjustments to the labour market parameters. Moreover, selecting parameters near their maximum/minimum values reduces the limitations of not only the quantitative but also the qualitative conclusions of the model.

6. Discussion and conclusion

In this paper, I supplement a basic macroeconomic agent-based model with a complex labour market, including such important components as the ability of workers to switch industries based on their skills, skill loss during unemployment, and the dependence of wages on skills.

The modelling results show, first, that the more complex model exhibits an unemployment scar on GDP. After a single-period aggregate 25% supply shock resulting in layoffs, a difference of approximately 3% between the trajectory of real gross domestic product in the shocked and unshocked scenarios persists even 20 quarters after the shock.

Second, this difference in GDP is driven by changes in only a few industries. These differences are shown to be statistically significantly related to skill levels and the average number of employees in each firm within the industry.

Third, training programmes for the unemployed help mitigate this difference. However, given that the shock has its greatest impact on only a few skill-intensive industries, a more personalised approach may be more effective. Targeted training of students in the industries experiencing the greatest difficulties in recruiting workers during the crisis achieves the same results as broader training programmes for the unemployed, but with a much smaller number of trainees.

A sensitivity analysis of the model's parameters shows that the conclusions are robust to small changes in the parameters. However, choosing implausibly large or implausibly small parameter values leads to changes not only in the quantitative but also in the qualitative conclusions of the model.

Several related research questions remain beyond the scope of this study and merit further exploration. First, examining the effects of a broader range of shocks could enhance our understanding of labour market distortions. However, further detailed selection of such shocks is required to eliminate their inherently uneven impact on different sectors or population groups and to avoid biased results. Second, the model assumes that the skill learning and degradation processes occur uniformly for all the agents in the model. However, the agents may have personal reasons for upgrading or downgrading (or not using) their skills. Such mechanisms may generate additional effects but raise significant challenges in choosing an adequate approach to modelling and calibration. Third, despite the overall representativeness of the skills survey used in this study, calibrating the skills using Russian data could refine the quantitative estimates and capture the specific characteristics of Russian society. However, as discussed earlier, obtaining such data from existing open sources is not feasible and requires further study. Fourth, although certain studies (Dawid et al., 2012, 2013) suggest a link between employee skills and firm performance, the existence of this link in reality remains debatable. For example, research by OECD (2026) suggests that higher skills may not lead to higher productivity because 1) the current job does not allow for the use of many skills that employees possess, 2) the distribution of tasks on the job may be associated not with the possession of specific skills but with various biases, such as gender bias, and 3) high performance requires a combination of skills. For example, high technical skills may not be very effective without communication skills. Thus, the impact of skills on productivity remains controversial and requires further detailed study beyond the scope of this study.

Thus, this study demonstrates that specific labour market processes have a significant and prolonged impact on the trajectory of real GDP and underscores the importance of including these processes in large-scale macroeconomic models. Indeed, as has been shown, omitting labour market difficulties can significantly distort the model conclusions even when analysing issues that are seemingly unrelated to the labour market.

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