INTERNATIONAL MONETARY FUND

# HUNGARY

## SELECTED ISSUES

August 2024

This paper on Hungary was prepared by a staff team of the International Monetary Fund as background documentation for the periodic consultation with the member country. It is based on the information available at the time it was completed on July 18, 2024.

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July 18, 2024

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**European Department**

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## CONTENTS

# MONETARY POLICY ANALYSIS WITH A QUARTERLY PROJECTION MODEL[1]

## A. Introduction

**1.      The calibration of monetary policy is particularly challenging at a time of large shocks to inflation and output.** Interest rates in Hungary rose sharply in response the significant increase in inflation to above 25 percent y/y in 2023-Q1 and large depreciation in the forint. As inflationary pressures have eased and the exchange rate has stabilized, the base rate has been reduced to 7.0 percent in June 2024 but remains restrictive. The Reuters survey of economists' forecasts indicates that the policy rate is expected to fall further to around 6¼ percent by the end of 2024.[2] Balancing the risks of loosening too quickly and inflation taking longer to sustainably return to target against those of loosening too slowly with larger costs to output requires careful calibration. The pace and extent of future easing depends on the drivers of recent inflation, the state of the economy, and lags in the transmission mechanism.

**2.      Models such as the IMF's Quarterly Projection Model (QPM) provide a quantitative guide to the calibration of monetary policy.** While easing inflation pressures suggest that qualitatively the monetary policy stance should be loosened over time, models provide a quantitative indication of the appropriate pace and extent. The QPM offers important features useful for monetary policy and scenario analysis. Interest rates are endogenous, reacting to changes in economic conditions. The projections for monetary policy and the economy are therefore internally consistent. The model is also forward-looking. So what matters is the expected paths for interest rates and inflation, not just rates today. The model can also be used to assess how large supply shocks to one sector – such as energy and other goods – spill over to sectors such as services. Such models are of course subject to uncertainties, particularly when the shocks are large and there are structural breaks. Nonetheless, they provide a useful quantitative benchmark, alongside judgement and other analysis, to inform the monetary policymaking process.

## B. Overview of the Quarterly Projection Model

**3.      The Quarterly Projection Model is one of the IMF's workhorse models for macroeconomic forecasting and monetary policy analysis.** It is a semi-structural new-Keynesian model, incorporating nominal rigidities and rational expectations. It therefore benefits from some of the theoretical insights of structural models but retains more flexibility, closeness to the data and simplicity than a fully micro-founded dynamic stochastic general equilibrium model (Carabenciov et al, 2008). It filters key macroeconomic variables into trends and gaps. Identifying appropriate trends, with the use of some judgement, is key to the performance of the model.

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[1] Prepared by Chris Jackson (RES).

[2] Median value of economists' responses to the Reuters survey conducted in June 2024.

4.       The standard QPM is comprised of four key equations, which are described in greater detail in Section E:

1) **An IS curve** that relates aggregate demand to real interest rates, credit conditions, and the exchange rate;
2) **A Phillips curve** that relates inflation to the output gap, exchange rate and relative prices;
3) **A policy or Taylor rule** that determines how interest rates respond to deviations in expected inflation from target and the output gap;
4) **An uncovered interest parity (UIP) condition** that relates the exchange rate to expected interest rate differentials and a risk premium.

5.       **The standard QPM is adapted to reflect some specific features of the Hungarian economy and post-Covid set of shocks.** Inflation is modelled in greater sectoral detail, including the separation of core goods and services, to capture differences in their drivers and dynamics and to model spillovers of shocks from one sector to another. In a multi-sector model, each sector's inflation dynamics depend not only on the aggregate output gap but also its price level relative to aggregate prices. The exchange rate risk premium is explicitly included in the policy rule given the importance of exchange rate fluctuations for monetary and financial stability.[3] The model also includes changes in credit spreads, as well as risk-free rates, which may be positive in the case of a credit supply shock or negative in the case of interest rate caps. The latter are particularly important in the case of Hungary given their widespread use since 2022 which hinders the transmission mechanism.

## C.   The QPM and Monetary Policy in the Baseline

6.       **The projections from the QPM are shown in Figure 1 under two assumptions**. The "baseline" projection is conditioned on a path for interest rates consistent with market participants' expectations for the first year of the forecast, as measured by the median of the Reuters poll of economists.[4] That implies that average quarterly interest rates fall to 6¼ percent in 2024-Q4 and 5¾ percent by 2025-Q2. The "unconstrained policy rule" projection instead allows interest rates to respond endogenously using the model's Taylor rule.

7.       **Conditioned on the market path for interest rates, the model projects that inflation picks up from 3.7 percent y/y in 2024 Q1 to 4.2 percent by the end of 2024, above the tolerance band of the target**. Part of this reflects the impact of increases in indirect taxes on fuel. But it also reflects a pickup in core inflationary pressures. Over the forecast, the current disinflationary impulses of falling commodity prices and the appreciation in the forint fade. This reveals an elevated rate of services inflation, which has slowed less than goods inflation. In addition to inherent price persistence, services inflation remains strong because prices are low relative to

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[3] A similar approach is used in Szilagyi et al (2013), although the current monetary policy model (Békési et al, 2016) does not include the exchange rate risk premium in the policy rule.

[4] The path for monetary policy is implemented using unanticipated shocks as anticipated shocks have a large effect on inflation and output, a version of the forward-guidance puzzle.

elevated real marginal costs. It implicitly reflects two mechanisms: past increases in goods and commodities prices feeding through to services as intermediate inputs, but also the delayed response of nominal wages to higher past inflation (Guerrieri, Marcussen, Reichlin and Tenreyro, 2023). These forces are captured by the low level of relative services prices. Despite weak aggregate output, services inflation therefore needs to remain elevated to bring relative prices back to trend.



**Figure 1. QPM Projections Under the Baseline Monetary Policy Path and an Unconstrained Policy Rule**
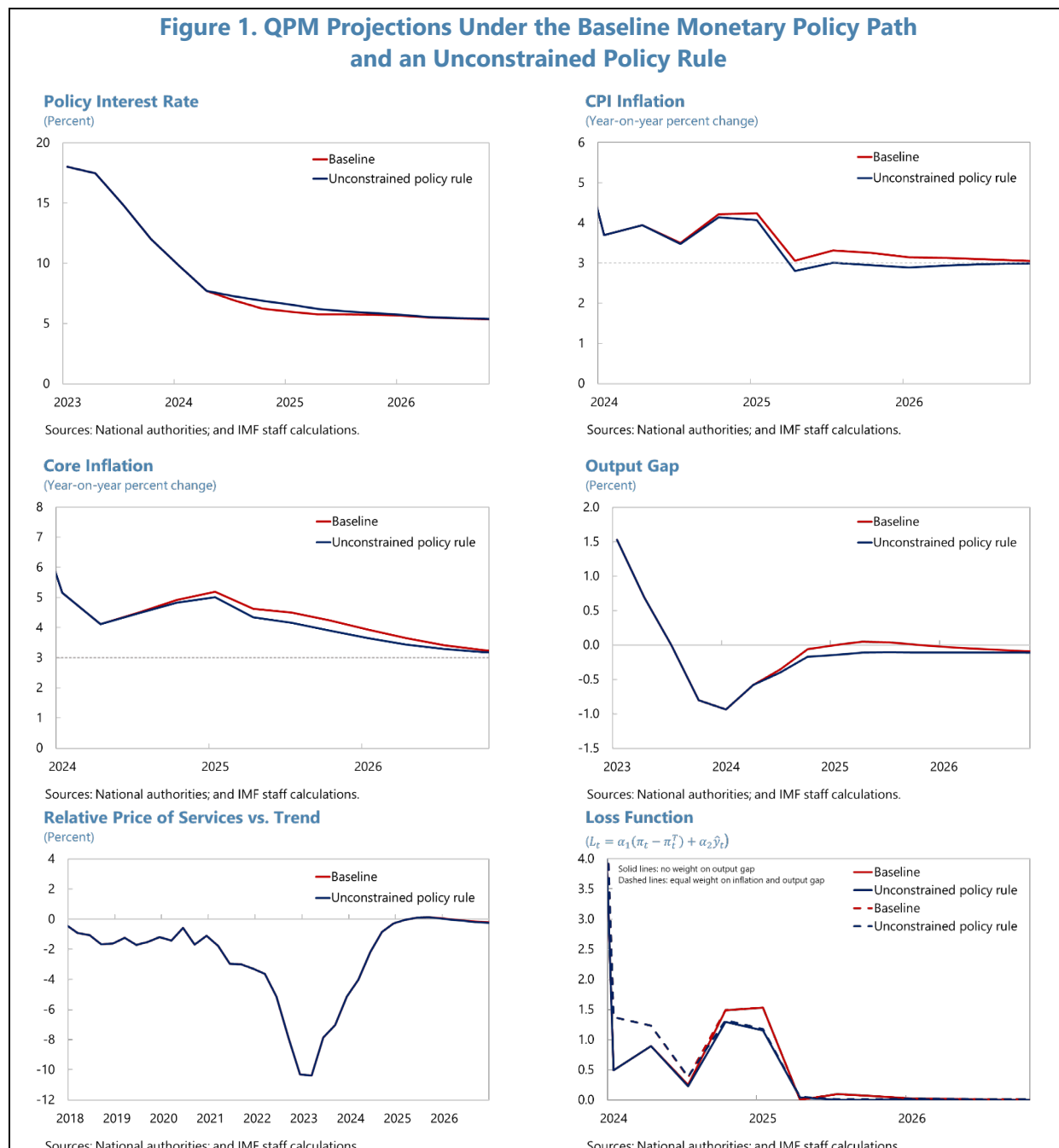
**8.      Beyond 2025-Q2, the path for interest rates switches to the model's policy rule.** As inflation remains above target, policy is somewhat restrictive through 2025 but significantly less so than in the previous year. By 2026, the ex-ante real policy rate settles at its neutral level of around 2 percent.

**9.** **The model's policy rule suggests that further interest rates should proceed cautiously and somewhat more gradually than the current market path**. This is because the model anticipates that inflation will remain somewhat elevated once the external disinflationary forces fade. Policy is therefore slightly more restrictive than the baseline to bring down inflation more quickly, producing a path for headline and core inflation that is closer to target on average in 2024-25. This comes at the cost of a slightly more gradual recovery. But even under a loss function with equal weights on deviations in inflation from target and the output gap, welfare is improved under the unconstrained policy rule path relative to baseline path for interest rates.

## D. Alternative Scenarios

**10.** **The model can also be used to assess the sensitivity of the path of interest rates to additional shocks to the economy and to the underlying behavior of inflation and output.**

**11.** **The behavior of the exchange rate is a key binding constraint on the path for interest rates given the sensitivity of inflation to the exchange rate.** While the forint has appreciated since its material depreciation in 2022, thanks in part to restrictive monetary policy, it remains sensitive to changes in risk sentiment. Figure 2 shows the model-implied paths for monetary policy if the exchange rate risk premium were to increase or fall temporarily. If the risk premium were to rise temporarily by 2½pp, weakening the currency, the model suggests that interest rates ought to stay elevated for longer. This partially mitigates the increase in inflation from the depreciation but at the cost of weaker growth. Likewise, if the risk premium were to normalize faster than projected it would allow interest rates to fall toward their neutral rate more quickly.



**Figure 2. Sensitivity of the Projections to Changes in the Exchange Rate Risk Premium**
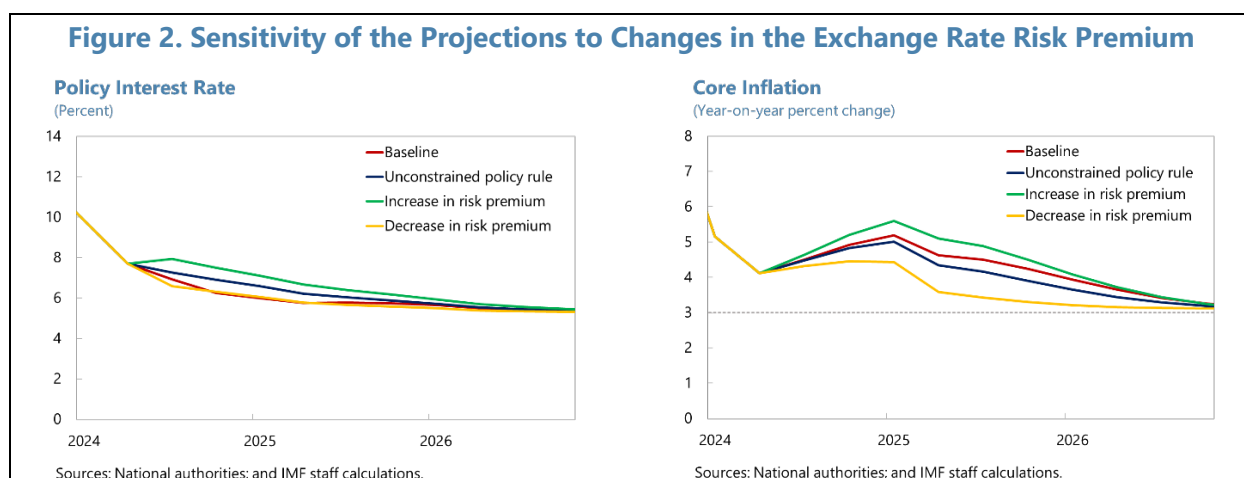
**12.** **A range of alternative model calibrations also suggest only a gradual reduction in interest rates.** The charts in Figure 3 illustrate how the policy path in the model would deviate under three different sensitivities: (i) stickier services inflation, potentially due to second-round effects of high inflation on wage growth and price indexation; (ii) a larger weight on output in the policy rule; (iii) longer lags of interest rates to activity (which may reflect weaker transmission

through the housing market in Hungary than in other economies[5]); and (iv) a lower estimate of the
trend real interest rate.



Figure 3. Sensitivity of the Projections to Changes in Model Parameters
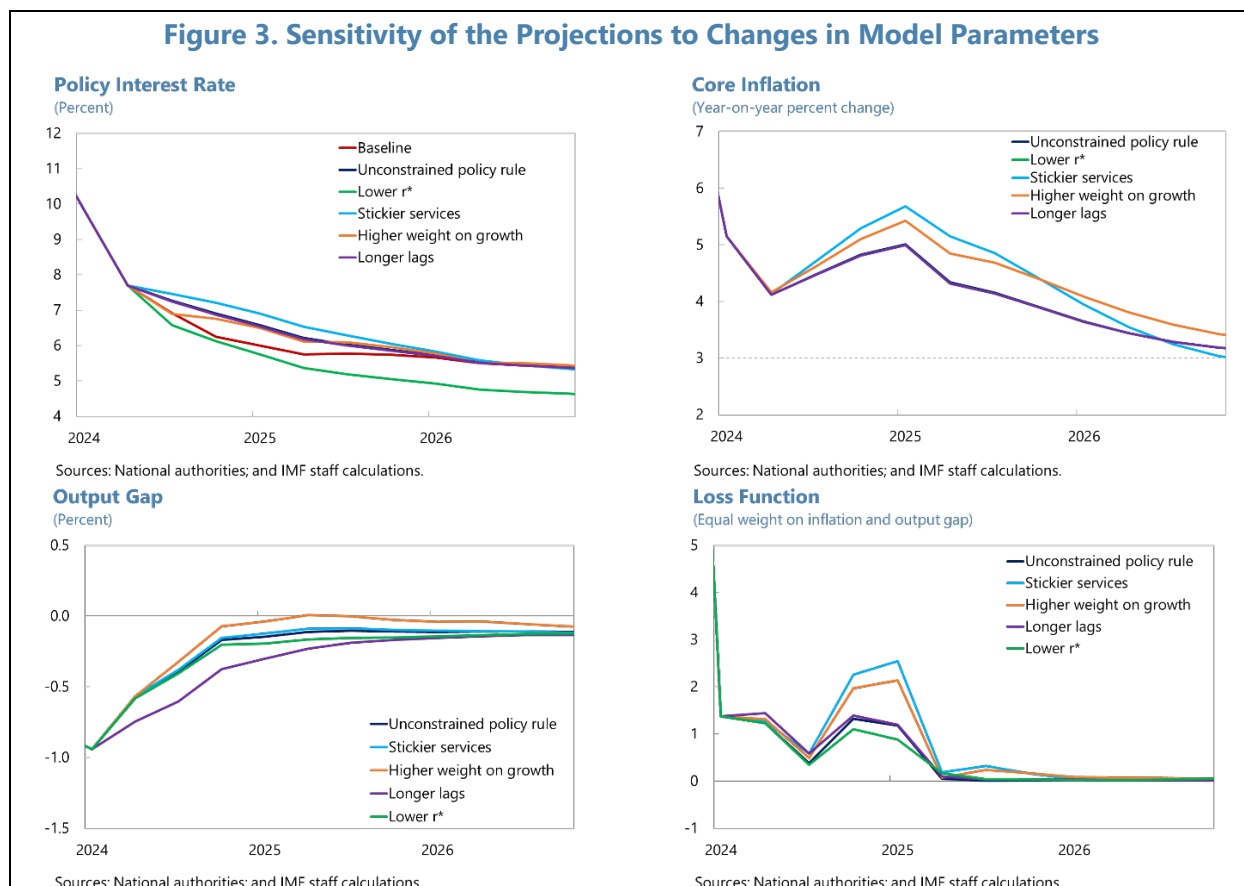
- In the first scenario, the persistence of services inflation is increased by 50 percent to reflect the potential for unusually strong second-round effects of high inflation via price indexation or high wage growth. Given current services inflation is elevated, this results in a higher inflation forecast. As a result, interest rates remain tighter through 2024-25 and do not reach their neutral level until 2026.

- The second scenario assumes that the policymaker places a higher weight on growth in the policy rule (equal to inflation). It also assumes that there is little interest rate smoothing. In this case, interest rates initially fall faster in 2024 than in the baseline, closing the output gap slightly faster. But it comes at the cost of higher inflation. And expectations of higher inflation ultimately mean that interest rates remain more restrictive than the baseline. Welfare is lower, despite stronger growth, even when weighing inflation and output deviations equally.

- The third scenario considers a model with longer lags of monetary policy to output. In this scenario, output takes longer to recover as the past high level of interest rates continues to

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[5] April WEO 2024, 'Feeling the Pinch? Tracing the Effects of Monetary Policy Through Housing Markets'.

weigh on output. This produces little change in the path for the policy rate because the slope of the Phillips curve in the model is low. As a result, the projection for inflation is little changed.

- The final scenario assumes that the trend real rate, or r*, is 1 percent lower than estimated by the model. This produces a lower path for interest rates over the projection but with little change to the paths for the output gap or inflation.

**13.      Given the incidence of large shocks in the recent past, it is also useful to consider the uncertainty around the central projections.** Figure 4 shows fan charts around the baseline projections for inflation and the policy rate. The bands around the forecast are created using a bootstrap approach. Residuals from the model's equations are sampled randomly with replacement and then used to shock the model in successive quarters of the projection.[6] Observations during 2020-21 are not sampled given the large changes in GDP and shocks during the peak Covid period. The fan chart for interest rates, however, is produced assuming no shocks to the future policy rate. Instead, monetary policy reacts only endogenously to the draw of shocks each period.[7]

### Figure 4. Fan Charts



**CPI Inflation**
(Year-on-year percent change)

**Effective Policy Rate**
(Percent)

Sources: National authorities; Haver Analytics; and IMF staff calculations.

Sources: National authorities; Haver Analytics; and IMF staff calculations.

*Note: the fan chart shows the distribution of projected outcomes based on random draws of past shocks and an endogenous monetary policy response to those shocks. Each band represents five per cent of the distribution. The outer bands show the tenth and ninetieth percent of the distribution.*

**14.      The fan charts are wide, suggesting that uncertainty around the projections is high. Communication around the likely future path of interest rates should convey this uncertainty.** The fan chart for inflation is also asymmetric, with the mean projection lying above the baseline. This reflects the incidence of large supply shocks increasing inflation in the recent data. To extent that the risk of such supply shocks remains, this implies that risks to the baseline inflation may be somewhat skewed to the upside. This suggests that monetary policy ought to loosen but cautiously while there is some chance that these shocks could persist or reoccur.

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[6] The residuals therefore capture any correlations across equations but are independent over time.

[7] The fan charts are also conditioned on the set of shocks underlying the baseline including those needed to deliver the market path for interest rates.

## E.   Impulse Response Functions

**15.      The model is calibrated to be broadly similar to external estimates.** Figure 5 shows the impulse responses from a monetary policy shock. A 1pp temporary but persistent increase in the policy rate reduces the level of output by around 0.15 percent and reduces inflation by a peak of 0.4pp, implying a low sacrifice ratio. Inflation also falls quite quickly, with the peak impact under a year. Both these features reflect the importance of the exchange rate channel in Hungary, consistent with the findings of Szilágyi et al (2013) and Vonnák (2007). In part, that is due to the large share of tradables in the CPI: 74 percent of the basket is goods compared to 55 percent in the euro area.

| Figure 5. Monetary Policy Shock | Figure 6. Core Goods Inflation Shock |
|---|---|
| (Percent; percentage) | (Percent; percentage) |



Sources: IMF staff calculations.
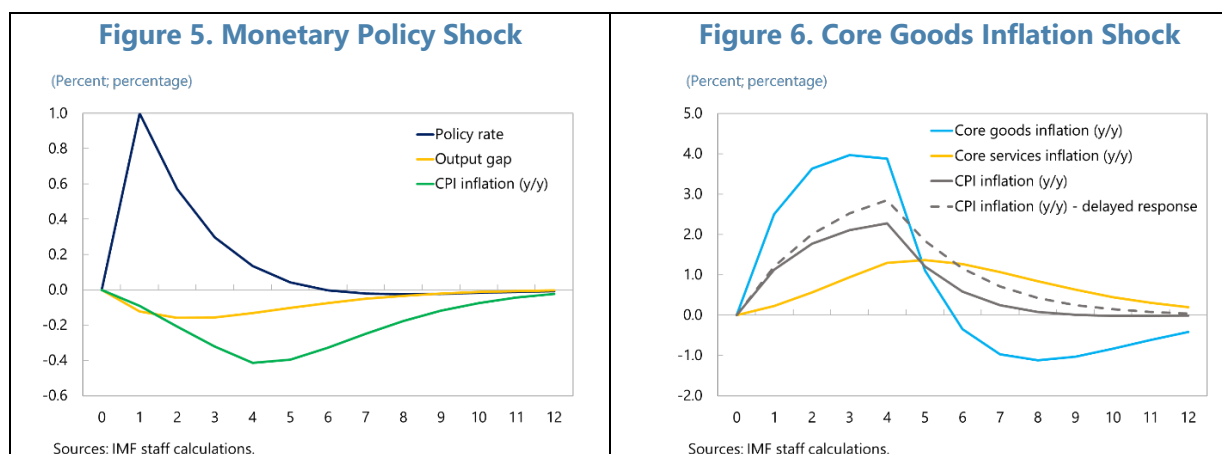
**16.      An important feature of the model is sectoral spillovers, which mean that temporary shocks in one sector affect inflation in other sectors.** Figure 6 illustrates the role of sectoral spillovers in the model. A cost-push shock in the core goods sector, such as those from supply bottlenecks, temporarily increases core goods inflation. But by increasing the overall price level, the shock to goods prices also implicitly leads nominal wages to increase as workers bid up their wages to restore their purchasing power. This increases marginal costs in the services sector, requiring services prices to increase. As a result, a temporary shock to the goods sector ultimately induces a smaller but persistent increase in services inflation, delaying the return of inflation to target. Despite it being a relative price shock, tighter monetary policy ultimately helps bring inflation back to target faster. With a monetary policy response, CPI inflation returns to target two years. If the policy response is delayed by a year, however, then inflation takes an additional year to return to target.

## F.   Conclusion

**17.      Following a period of large interest rate reductions, the projections from the QPM suggest that the next phase of monetary policy normalization should proceed cautiously and more gradually.** This is because the model expects the pace of disinflation to slow as external disinflation forces fade and second-round effects continue to push up services inflation. A more gradual reduction in interest rates than embedded in recent market expectations would deliver a slightly smaller pick-up in inflation at the end of 2024 and inflation closer to target in 2025. There are, of course, caveats around these projections, particularly when the outlook is uncertain. For

instance, the model may misidentify the size of key "gaps" such as the output or real rate gaps. While the model has been adapted to capture some distinct features of the post-Covid inflation surge, it is unlikely to capture all of them, particularly given the model's reduced form. As such, results from the model should be used alongside other forms of analysis and expert judgement in determining the optimal path of monetary policy. Data should be watched keenly to assess the realism of the model's projections.

## G. Model Equations

**18.**     The model consists of four main sets of behavioral equations:

- **Aggregate demand and supply**

The output gap ($\hat{y}_t$) is a function of its lag and its expected value, a monetary conditions index ($mci_t$), the foreign output gap ($\hat{y}_t^*$) and aggregate demand shocks ($\epsilon_t^{\hat{y}}$). The monetary conditions index is comprised of the real interest rate gap ($\hat{r}_t$), a credit risk premium ($cprem_t$) and deviations in the real exchange rate from its trend ($\hat{z}_t$). The credit risk premium is an exchange rate or country-specific risk premium and a domestic premium. The country risk premium explains deviations in the trend real exchange rate from relative interest rate differentials. The domestic premium reflects the difference between interbank interest rates and bank lending rates charged to the real economy.

$$\hat{y}_t = b_{1a}\hat{y}_{t-1} + b_{1b}E_t\hat{y}_{t+1} - b_2 mci_t + b_3\hat{y}_t^* + \epsilon_t^{\hat{y}}$$

$$mci_t = b_4(\hat{r}_t + cprem_t) + (1 - b_4)(-\hat{z}_t)$$

- **The Phillips curve and relative prices**

Inflation is disaggregated into five sectors: core services, core goods, unprocessed food, fuel, and regulated prices (including gas and electricity). Each sector differs in its degree of price stickiness and sensitivity to the output gap and external costs. In addition, in a multi-sector model each sector's inflation dynamics depend not only on the aggregate output gap but also its relative price gap (Woodford, 2003). A shock to marginal costs in the goods sector pushes up aggregate inflation, which in turn increases nominal wages (to restore real wages) and marginal costs in the services sector. This allows for second-order spillovers of shocks in one sector to another through relative price adjustments.

Quarterly annualized inflation in each sector $j$ is modelled using a new-Keynesian hybrid Phillips curve, in which inflation depends on past and expected inflation, real marginal costs and cost-push shocks:

$$\pi_t^j = \alpha_{j1}\pi_{t-1}^j + (1 - \alpha_{j1})E_t\pi_{t+1}^j + \alpha_{j2}rmc_t^j + \epsilon_t^j$$

The real marginal cost in sector $j$ is given by:

$$rmc_t^j = \alpha_{j3}\hat{y}_t + (1 - \alpha_{j3})\hat{z}_t - \widehat{rp}_t^j \qquad \text{for } j = services$$

$$rmc_t^j = \alpha_{j3}\hat{y}_t + (1 - \alpha_{j3})((1 - \alpha_{j4})\hat{z}_t + \alpha_{j4}\widehat{rp}_t^{noncore}) - \widehat{rp}_t^j \qquad \text{for } j = core\ goods$$

$$rmc_t^j = \alpha_{j3}\hat{y}_t + (1 - \alpha_{j3})(\hat{z}_t + \widehat{rwfood}_t) - \widehat{rp}_t^j \qquad \text{for } j = unprocessed\ food$$

$$rmc_t^j = \alpha_{j3}\hat{y}_t + (1 - \alpha_{j3})(\hat{z}_t + \widehat{rwoil}_t) - \widehat{rp}_t^j \qquad \text{for } j = fuel$$

$$rmc_t^j = \alpha_{j3}\hat{y}_t + (1 - \alpha_{j3})(\hat{z}_t + \widehat{rwnatgas}_t) - \widehat{rp}_t^j \qquad \text{for } j = regulated$$

In the core sectors, real marginal costs are determined by the output gap, the real exchange rate gap and relative prices. Real marginal costs for core goods includes the relative price of non-core CPI to capture food and energy prices as key direct inputs. Real marginal costs for non-core sectors also include gaps in the relevant real commodity prices.

The price series are aggregated together using their respective CPI weights, allowing for some persistent measurement error $\eta_t$:

$$p_t = w^S p_t^S + w^{CG} p_t^{CG} + w^F p_t^F + w^{Fuel} p_t^{Fuel} + w^{Reg} p_t^{Reg} + \eta_t$$

The relative price gaps are constrained to sum to zero:

$$0 = w^S \widehat{rp}_t^S + w^{CG} \widehat{rp}_t^{CG} + w^F rp_t^F + w^{Fuel} \widehat{rp}_t^{Fuel} + w^{Reg} \widehat{rp}_t^{Reg} + \eta_t$$

- **Interest rates and the policy rule**

Monetary policy is set according to a Taylor rule:

$$i_t = g_1 i_{t-1} + (1 - g_1)(i_t^n + g_2(E_t \pi_{t+4}^{CT} - \bar{\pi}_{t+4}) + g_3 \hat{y}_t + h_1 \Delta prem_t) + \epsilon_t^i$$

$$i_t^n = \bar{r}_t + E_t \pi_{t+4}^{CT}$$

$$\bar{r}_t = \rho^{\bar{r}} \bar{r}_{t-1} + (1 - \rho^{\bar{r}})(10Y_t^{BUBOR} - \pi_t^T) + \epsilon_t^{\bar{r}}$$

The Taylor rule is standard exception for the inclusion of the term $h_1 \Delta\, prem_t$ which reflects the fact that the central bank may place some weight on the stabilization of the exchange rate, as well as inflation and output. Large fluctuations in the currency may pose financial stability as well as price stability risks. The trend real interest rate is pinned down using the 10-year BUBOR interest swaps rate. The policy rule also uses a measure of inflation that strips out indirect taxes, $\pi^{CT}$, given these have only a temporary effect on inflation.

- **Uncovered interest rate parity and the exchange rate**

The nominal exchange rate ($s_t$) is determined by a UIP condition with a backward-looking element to capture stickiness in the adjustment of the exchange rate. A more positive value indicates a depreciation. Growth in the trend real exchange rate ($\Delta\bar{z}_t$) is a weighted average of its lag and a steady-state value. The exchange rate premium is additional premium investors for holding the currency over and above the returns from the real interest rate differential.

$$s_t = (1 - e_1)E_t s_{t+1} + e_1\left(s_{t-1} + \frac{2(\bar{\pi}_t - \bar{\pi}_t^* + \bar{z}_t)}{4}\right) + (i_t - i_t^* + prem_t) + \epsilon_t^s$$

$$\Delta\bar{z}_t = \rho^z \Delta\bar{z}_{t-1} + (1 - \rho^z)\Delta\bar{z}^{SS} + \epsilon_t^{\bar{z}}$$

- **Foreign variables**

The world block consists of global real commodity prices – food, oil and natural gas. Trends are estimated for each real commodity price, with the gaps relevant for domestic price pressures. The

world economy is assumed to be summarized by variables for the euro area given Hungary's close trading links with the block. These variables include GDP, headline inflation, the ECB's policy rate and an output gap and are conditioned on the projections for these variables in the April 2024 WEO. The dynamics of the world variable gaps are generally modelled as AR(1) processes.

## H.  Calibration and Impulse Responses

**19.**      The model is calibrated to produce plausible impulse responses that also correspond with those from the literature, including Szilágyi et al (2013) and Békési et al (2016). The main parameters are summarized in **Table 1**. The baseline projections use the calibrated model. But as a cross-check select important parameters are estimated over 2006-2024 Q1 using Bayesian techniques, using the calibrated values as priors. These are reported in the adjacent column and in most cases are close to the calibrated values.

<div align="center"><b>Table 1. Hungary: QPM Parameters</b></div>

| Parameter | | Value | Estimated | Parameter | | Value | Estimated |
|---|---|---|---|---|---|---|---|
| **IS curve** | | | | **Policy rule** | | | |
| Persistence | $b_{1a}$ | 0.5 | 0.43 | Interest rate smoothing | $g_1$ | 0.7 | 0.73 |
| Expected output | $b_{1b}$ | 0.05 | 0.05 | Weight on inflation deviation | $g_2$ | 1.2 | 1.06 |
| Interest rate channel | $b_2$ | 0.1 | 0.10 | Weight on output gap | $g_3$ | 0.25 | 0.31 |
| External demand | $b_3$ | 0.3 | 0.40 | Weight on exchange rate premium | $h_1$ | 0.2 | |
| Weight on real rate gap in monetary conditions index | $b_4$ | 0.8 | | | | | |
| **Core services Phillips curve** | | | | **Core goods Phillips curve** | | | |
| Persistence | $\alpha_{11}$ | 0.4 | 0.37 | Persistence | $\alpha_{21}$ | 0.4 | 0.52 |
| Real marginal costs | $\alpha_{12}$ | 0.1 | 0.07 | Real marginal costs | $\alpha_{22}$ | 0.1 | 0.09 |
| Loading on output gap in real marginal costs | $\alpha_{13}$ | 0.75 | | Loading on output gap in real marginal costs | $\alpha_{23}$ | 0.2 | |
| | | | | Loading on non-core costs | $\alpha_{24}$ | 0.75 | 0.83 |
| **Unprocessed food Phillips curve** | | | | **Fuel Phillips curve** | | | |
| Persistence | $\alpha_{41}$ | 0.5 | 0.27 | Persistence | $\alpha_{41}$ | 0.3 | 0.29 |
| Real marginal costs | $\alpha_{42}$ | 0.1 | 0.15 | Real marginal costs | $\alpha_{42}$ | 0.4 | 0.13 |
| Weight on output gap in real marginal costs | $\alpha_{43}$ | 0.3 | | Loading on output gap in real marginal costs | $\alpha_{43}$ | 0.0 | |
| **Regulated prices Phillips curve** | | | | **Exchange rate** | | | |
| Persistence | $\alpha_{15}$ | 0.1 | | Exchange rate persistence | $e_1$ | 0.3 | |
| Real marginal costs | $\alpha_{25}$ | 0.2 | | | | | |
| Loading on output gap in real marginal costs | $\alpha_{35}$ | 0.9 | | | | | |

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# HUNGARY'S CORPORATE SECTOR RISK: A MACHINE LEARNING APROACH[1]

## A. Introduction

**1.      In recent years, Hungary's non-financial corporations were confronted with multiple shocks.** Global and domestic supply and demand disruptions caused by the pandemic resulted in a significant contraction of Hungary's export-oriented economy, ending a period of steady growth over 2016-2019. Russia' war in Ukraine and the resulting pressures on energy prices further reduced households' disposable income and subjected firms to significant cost pressures. The inflationary pressures stemming from these shocks necessitated a historic tightening of monetary policy. With market interest rates peaking at around 18 percent, firms' borrowing costs rose markedly, while the post-pandemic recovery in demand became subdued as monetary policy transmission worked its way through the economy.[2]

**2.      Despite these shocks, the Hungarian corporate sector proved quite resilient.** The probability of default (PD) estimates for median Hungarian listed firms increased markedly at the onset of the pandemic, almost to the levels observed during the global financial and European crises (top left panel). This occurred as firms' financial ratios deteriorated (top right panel) and growth plummeted (bottom left panel). Such risks eased significantly in 2021, however, as the economy began to recover and firms' profitability and debt-servicing capacity improved. The median PD picked up again in 2022, although at a much more moderate pace, on the back of continued forint depreciation and rising interest rates and sovereign risk premia (bottom right panel).



**Figure 1. Hungary's Corporate Sector Risk and Selected Firms' Characteristics and Macroeconomic Variables**

Probability of Default (PD) of Listed Non-Financial Firms
(Median)
Sources: NUS-CRI; and IMF staff calculations.

Median PD and Selected Firms' Characteristics
(Median; percent)
Sources: NUS-CRI; Orbis; and IMF staff calculations.
Note: ROA=return on assets, ICR=interest coverage ratio, CR=current ratio.

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[1] Prepared by Jakree Koosakul (EUR) and Xuege Zhang (MCM). The authors are grateful to Kevin Wiseman for sharing the code previously used to examine corporate sector risks in the context of Mexico 2023 Article IV Staff Report.

[2] It is worth noting that despite the historic increase in the monetary policy rate, a range of subsidized programs were introduced to help shield companies since the breakout of the pandemic. In addition, a significant portion of market-based loans appear to depend on long-term yields rather than the policy rate. These factors would imply that the effective loan rates for companies did not increase as much as the policy rate.

**Figure 1. Hungary's Corporate Sector Risk and Selected Firms' Characteristics and Macroeconomic Variables (Concluded)**

Real GDP Growth and EUR/HUF Exchange Rate
(Percent)

10-Year Government Bond Yields and CDS Spreads
(Percent; basis points)

Sources: National authorities; Haver Analytics; and IMF staff calculations.

Sources: Haver Analytics; and IMF staff calculations.

**3.      Against this backdrop, this annex utilizes machine learning techniques to better understand the evolution of risks in Hungary's corporate sector.** The objectives are twofold: i) explore the general determinants of firms' PDs over the past two decades, based on both firm-specific and macroeconomic factors, and ii) examine more specifically the influence of these determinants on firms' PDs during and after the pandemic. As is standard in the literature, our focus is on non-financial corporations (NFCs). Due to data availability, the analysis is based on NFCs listed in Hungary's stock market (and extended to include other CESEE countries as a robustness check).

## B.   Data and Methodology

**4.      The analyses are based on data from several sources over the span of two decades.** The estimates on firms' PDs are obtained from the Credit Research Initiative, National University of Singapore (NUS-CRI).[3] Such PDs are transformed through a logistic (logit) function.[4] Firms' financial ratios are calculated based on balance sheet data from the Orbis database.[5] To account for the impact of macroeconomic factors, data on Hungary's GDP growth, 10-year government bond yields, CDS spreads, and the EUR/HUF exchange rate are obtained from Haver.[6] The sample period is 2000-2022. The matched sample of firms contains 527 firm-year observations covering 55 unique firms, with 24 firms present on average each year. Inspection into the characteristics of these firms indicates that a range of industries are well represented, although given the listed nature of these firms, the sample focuses on large corporations in the Hungarian economy. Due to the rather small sample, a robustness exercise conducted in the final section of this annex relies on an expanded sample of listed firms not only in Hungary, but also in seven other CESEE countries, namely Bulgaria,

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[3] For more details on the measure, which is based on the forward intensity model of Duan et al. (2012), see CRI-NUS (2022)

[4] The choice of the logit transformation ensures that the predicted PD falls within the [0,1] interval.

[5] To clean firms' balance sheet data, we apply the procedure proposed by Kalemli-Ozcan et al. (2015).

[6] The choice of macroeconomic variables roughly follows a similar study done on Mexican corporates in the Mexico 2023 Article IV Staff Report.

Croatia, Czech Republic, Poland, Romania, Slovakia, Slovenia. This brings the number of firms and firm-year observations to 1,182 and 10,086, respectively.

**5.      Machine learning techniques are utilized.** Relative to more traditional regression techniques, machine learning methods offer several advantages, including their ability to handle non-linear relationships, non-standard distributions, data gaps, and outliers that are prevalent in firms' financial ratios, and interaction effects between explanatory variables. Without a strong prior on which specific machine learning models may be appropriate, a variety of candidate models with different levels of flexibility and complexity are considered. These include elastic net, decision tree, K-nearest neighbors, and random forest, which are the more commonly used algorithms to model continuous dependent variables in economics.[7]

**6.      Candidate models are evaluated based on out-of-sample performance.** To avoid overfitting, the selection of the final machine learning method for modelling Hungarian firms' PDs is based on evaluating their out-of-sample predictive performance through cross-validation. The estimation sample is divided into subgroups or "folds", with one fold removed to be used as a validation set and the remaining folds used in the estimation of the model. The model's performance is then evaluated based on its predictive power over the validation fold. This is repeated for each fold and the results across all folds are averaged to arrive at an overall metric of performance. This cross-validation exercise is conducted by dividing folds based on random allocation, firm size, and time.

**7.      The random forest model has the best predictive performance.** Through the horse race, we find the random forest model to produce the highest value of the average coefficient of determination (akin to $R^2$ in the OLS regression context) among the four candidate models (Figure 2). This is true under all combinations of cross-validation sampling method.



**Figure 2. $R^2$ for Candidate Models Under Different Cross-Validation Groups**

Source: IMF staff calculations.
Note: enet = elastic net, knn = K-nearest neighbors, tree = decision tree, and rf = random forest.

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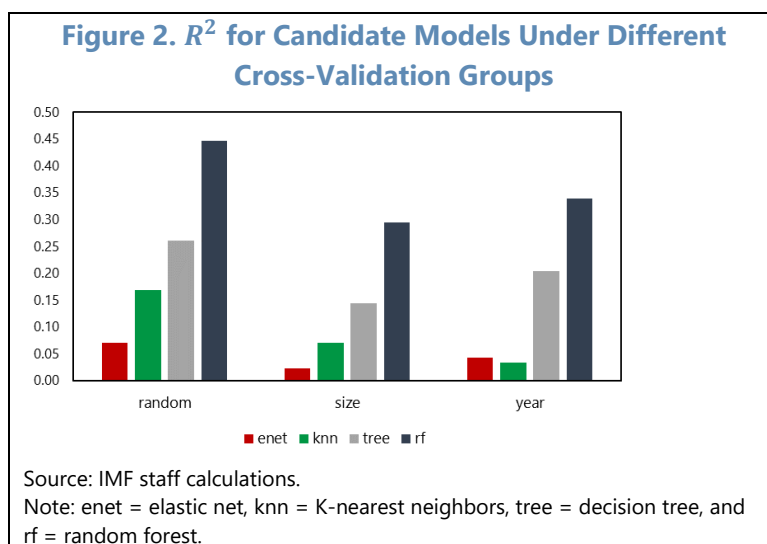
[7] Athey and Imbens (2019) provide a useful reference on the description and use of these models in economics.

## C. Determinants of Corporate Sector Risk

**8.      Both firm-specific and macroeconomic variables are found to be important determinants of firms' PDs.** As with other non-linear machine learning models, results from the random forest model can be summarized via Shapley values, which represent additive contributions of each factor to the predicted values of the dependent variable. A "beeswarm" plot provides a useful visual representation of each factor's contributions based on such values, where the variables are ranked in order of their average absolute contribution to risk assessment and where the color of each dot represents high (in red) or low (in blue) values for the variable in question. From Figure 3, return on assets (ROA), firm size, and cash equivalents to current liabilities (CE/CL) are the top three most important variables in the model, highlighting the importance of firm profitability, size, and liquidity buffers. The direction of the effects is as expected, with high risks associated with low values of these variables. On the macro side, sovereign risk premia, captured by the CDS, appears as the fourth most important factor, with high risks correctly associated with high values. Long-term interest rates and the value of the currency are found to play a relatively minor role, although their variations appear to explain some of the variations in the predicted PDs. By contrast, the role of GDP growth in predicting corporate risk seems very limited, potentially reflecting the positive correlation between growth and firms' profitability ratios that are also included in the model.



Figure 3. Contributions to Risk Assessment

Source: IMF staff calculations.
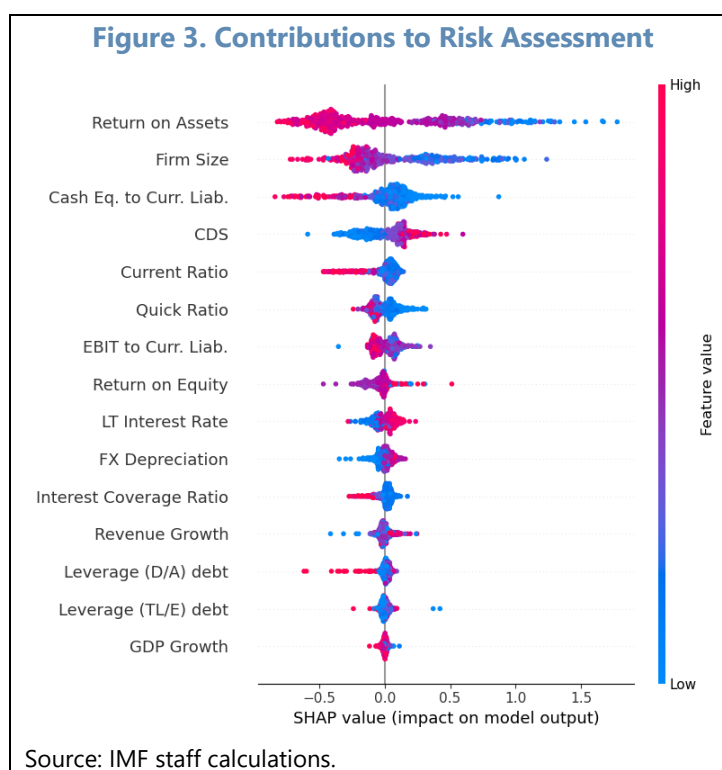
**9.      Plots of Shapley values for individual variables also highlight some non-linearity and interaction effects.** Figure 4 displays plots of Shapley values for the top two firm-specific and macroeconomic variables. There appears to be significant non-linearity in the effects on risk for all four variables. More specifically, the contributions to predicted PDs from ROA and firm size fall sharply when returns become positive or firms are sufficiently large. Similarly, the contributions from

sovereign risk premia and long-term interest rates increase substantially when CDS spreads rise above around 170 and when bond yields are higher than 7 percent. In addition, some interaction effects are evident. In particular, the reduction in the contributions of ROA and firm size to predicted PDs is more pronounced for firms with higher CE/CL (red dots). Put differently, the beneficial effects of higher profitability and larger size appear to be greater for firms with higher liquidity buffers. Similarly, larger firms (red dots) also appear to benefit more in terms of the risk reduction from a decline in long-term interest rates than smaller firms.



**Figure 4. Shapley Values of Selected Firm-Specific and Macro Variables**

Source: IMF staff calculations.
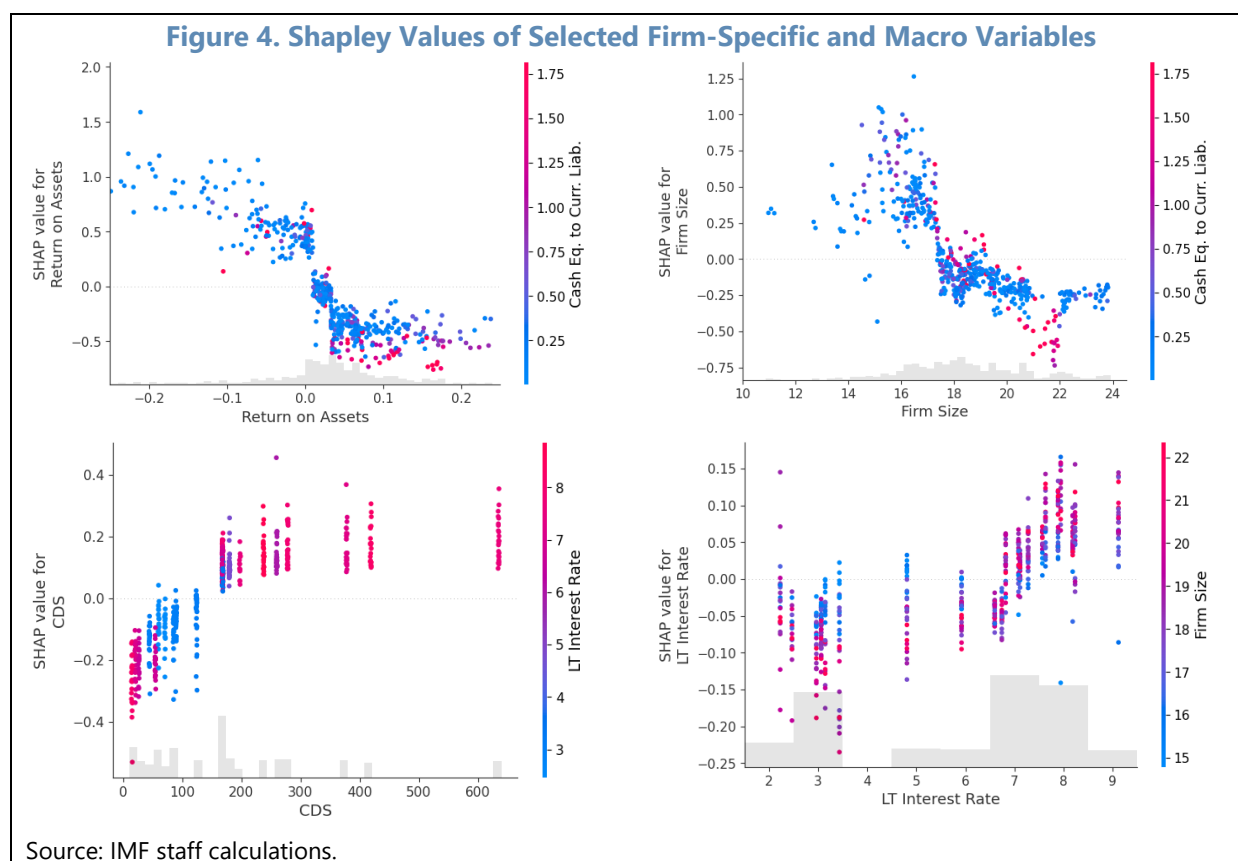
## D. Risk Evolution Through the Pandemic and High Interest Rates

**10. Risk indicators deteriorated across the board at the onset of the pandemic before improving one year after the pandemic.** Since Shapley values are additive, they can be averaged across firms for each variable for a given year. The difference in the average Shapley values across two years for a given variable hence allows us to capture the contribution of such a variable to the change in the predicted PD between the two years. The waterfall charts below provide information on the main contributors to the change in the predicted PDs during and after the pandemic. At the onset of the pandemic in 2020, the left-hand panel of Figure 5 shows a deterioration of key risk factors across the board. In particular, deteriorating profitability contributed the most to the observed rise in Hungarian corporate sector risk in 2020. Other firm-specific and macro factors, namely firms' liquidity buffers and size, GDP growth, and sovereign risk premia also played a role, although to a limited extent. The right-hand panel then shows reversals in the contributions of risk

factors in 2021, with an improvement in firms' profitability playing the most significant role in reducing corporate sector risk, followed by a decline in CDS spreads and improvements in revenue growth and GDP growth.

**Figure 5. Contributions to Change in Average Predicted PD During the Pandemic**



Source: IMF staff calculations.

Note: in the left-hand panel, the average value of the logit PDs across all firms in 2021 is normalized to 0, such that the sum of the individual bars captures the change in the average logit PD across firms between 2021 and 2022. The same treatment applies to the average value of the logit PDs across all firms in 2022, in the right-hand panel.

**11.      While firm-specific risk factors continued to improve in 2022, their beneficial effects were more than offset by higher interest rates and rising sovereign risk premia.** While successful at taming inflationary pressures, our analysis highlights the effects of the significant monetary tightening on corporate sector risk in 2022, especially since this occurred at a time of rising sovereign risk premia. Going forward, it would be important to continue monitoring interest rate and maturity risks carefully, since a significant portion of corporate loans are set to mature within the next few years and could be repriced at higher interest rates.

**Figure 6. Contributions to Change in Predicted Logit PD Between 2021-2022**



Source: IMF staff calculations.

Note: the average value of the logit PDs across all firms in 2021 is normalized to 0, such that the sum of the individual bars captures the change in the average logit PD across firms between 2021 and 2022.
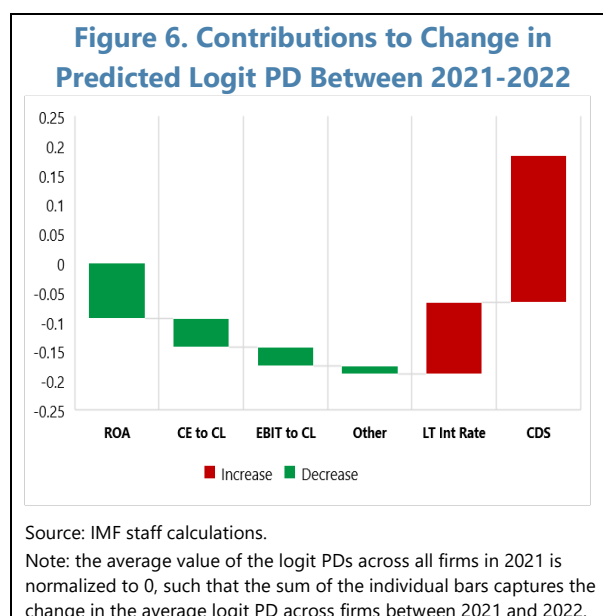
## E. Robustness Check

**12.** **Our baseline results are robust to including an expanded sample of countries.** Two

potential issues with respect to the baseline
sample are worth highlighting. First, the sample
contains a relatively limited number of firms. This
potentially limits the variations of both the
dependent and explanatory firm-specific
variables that would otherwise result in a more
precise identification of the effects of different
factors. Second, the focus on only one country
also implies relatively limited variations in the
values of macroeconomic variables, with each
variable only having just over 20 likely non-
independent observations. To address these
issues, the baseline exercises are replicated based
on an expanded sample of countries. As shown in
the charts below, the baseline results are robust
with respect to both the general determinants of
credit risk as well as the assessment on the
evolution of Hungary's corporate sector risk
during and after the pandemic.

**Figure 7. Contributions to Risk Assessment**
(Expanded Sample)
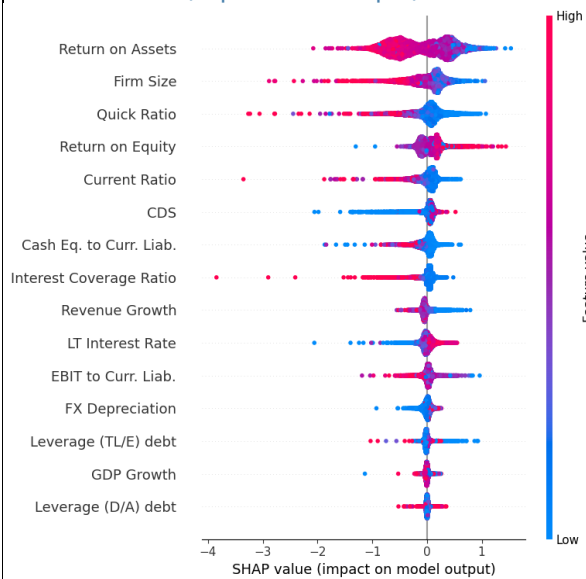


Source: IMF staff calculations.

**Figure 8. Shapley Values of Selected Firm-Specific and Macro Variables**
(Expanded Sample)

**Figure 8. Shapley Values of Selected Firm-Specific and Macro Variables (Concluded)**
(Expanded Sample)

Source: IMF staff calculations.

**Figure 9. Top Three Contributors to Hungary's Corporate Sector Risk Evolution**
(Expanded Sample)

Source: IMF staff calculations.
Note: While the model is estimated based on the expanded country sample, the results in this figure are computed specifically based on the Shapley values for Hungarian firms in the sample, and are hence Hungary-specific.

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# REGIONAL DISPARITIES IN HUNGARY: DRIVERS AND IMPLICATIONS OF THE DIGITAL AND GREEN TRANSITIONS[1]

## A.  Introduction

**1.      Hungary is gradually converging to the average income level of the EU.** Hungary's per capita income has been steadily rising over the last two decades, reaching 76 percent of the EU average in 2022, up from 66 percent in 2010 (Figure 1, left panel). Integration into global value chains—particularly Germany's automobile manufacturing sector—and increased foreign direct investment (FDI) inflows in recent years toward the electric vehicle (EVs) and battery production sector continue to play a significant role in facilitating Hungary's income convergence.

**2.      However, within Hungary, regional income disparities remain persistently high**. Despite the national progress towards the average EU income level, regional income disparities remain persistently high (Figure 1, right panel) as Budapest outpaces the rest of the country while growth remains low and stagnant in the least developed southern and northern regions. Beyond growth, these lagging regions continue to underperform the national average on several dimensions, including education, digitalization, infrastructure, and health outcomes (European Commission, 2023)[2].

**Figure 1. Regional Income Disparities and Convergence in Hungary**



Sources: Eurostat; and IMF staff calculations.

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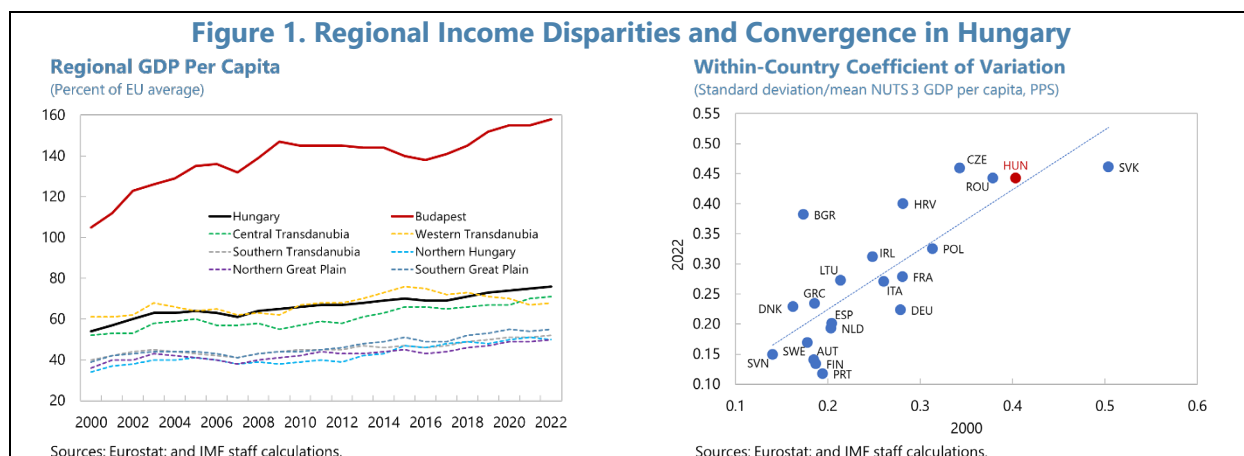
[1]Prepared by Augustus J. Panton (EUR).

[2] This is despite significant inflows of EU cohesion funds for regional integration—up to 2 percent of GDP annually—since joining the EU in 2014 (EU, 2024): Ninth report on economic, social and territorial cohesion.

**3.      The twin digital and green transitions may widen regional disparities and slow the**

**pace of income convergence.** The ongoing digital and green transitions may deepen disparities among regions on at least two fronts. First, like elsewhere in the EU, poorer Hungarian regions lack the high skill requirements of the green and increasingly digitalized economic environment (Figure 2), potentially widening the productivity gaps relative to richer regions (Maucorps and others, 2023). Second, these lagging regions are also more carbon intensive (per unit of output) than their higher-income counterparts, exposing them to more structural challenges in the transition to carbon neutrality (OECD, 2023). In essence,

**Figure 2. Digital and Carbon Intensities Across EU NUTS 2 Regions**

(Log of digitally-skilled workforce; tons of CO2 equivalent per 1000 euros)



Sources: European Commission: EU RCES Database; Eurostat; and IMF staff calculations.

workers in poorer and carbon-intensive regions, most of whom are not highly skilled, remain exposed to unfavorable labor market outcomes stemming from the digital and green transitions. This could amplify inter and intra-regional disparities absent targeted policy interventions.
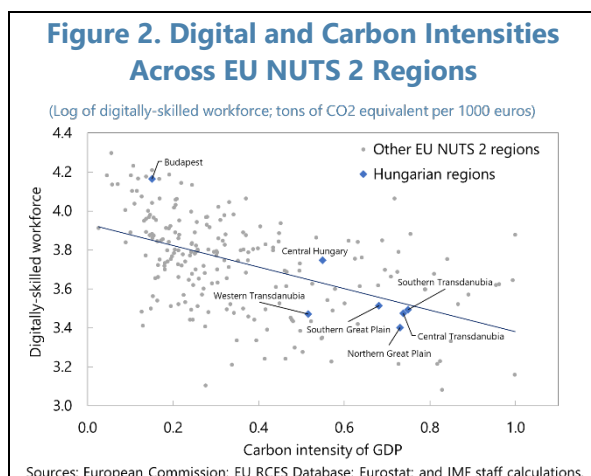
**4.      The analysis in this paper employs beta convergence and growth decomposition techniques to pin down the drivers of regional disparities and slow income convergence in Hungary**. The goal of the analysis is twofold. First, it examines the key drivers of regional income disparities in Hungary during the last two decades. To this end, a standard growth decomposition framework is employed to unpack how different growth components may have affected regional income disparities while highlighting heterogeneities across regions. Second, regional disparities are viewed through the lens of the digital and green transitions, with emphasis on how targeted policy interventions could prevent these major structural transformations from amplifying existing gaps.

**5.      The rest of the paper is structured as follows.** The next section analyzes regional income convergence and the drivers of Hungary's uneven growth using formal beta convergence and growth decomposition frameworks. Section three assesses Hungary's preparedness for the digital transition, focusing on how uneven digitalization (and adoption of artificial intelligence) may exacerbate income disparities, and examines the challenges of the green transition and the implications for regional income convergence. The fourth section sums up the paper with conclusions and policy recommendations.

## B.   Drivers of Regional Disparities

**6.      A standard beta convergence framework is used to examine the extent of heterogeneity in regional income convergence in Hungary.** As stylized in Figure 1, regional income convergence in Hungary has been slow and uneven amid low and stagnant growth in poorer regions while high income regions push ahead, widening the regional income gap over time.

Following the literature (Barro and Sala-i Martin, 1992; Sala-i Martin, 1996), a standard beta convergence[3] is used to examine whether Hungary's least-developed regions have been growing faster than their high-income counterparts to eventually catch up. This is formally estimated as

$$\Delta y_{r,t} = \alpha + \beta y_{r,t-1} + \varepsilon_{r,t} \qquad (1)$$

where $\Delta y_{r,t}$ and $y_{r,t-1}$ represent the average annual growth of regional per capita GDP and its initial level respectively. An estimated negative $\beta$ coefficient implies regional income convergence—that is, higher initial per capita income level is associated lower growth, and vice versa. This allows regions starting with lower income levels to eventually converge to their higher income counterparts. With region and time fixed effects added, the framework is used to examine conditional beta convergence among Hungary's NUTS 3 regions during the last two decades (2000-2019). The results are summarized in Table 1.

**7.      Hungary's regional growth dynamics are characterized by heterogeneous patterns of convergence and divergence.** The results in Table 1 confirm the stylized facts presented in Figure 1 with two nuances. First, at the national level, the existence of beta convergence is confirmed under different model specifications—controlling for time invariant factors (e.g., common global economic or policy shocks) and regional specificities (e.g., geographical location; institutional quality). Second, at the sub-national (NUTS 3) level, growth dynamics are heterogeneous, with poorer regions growing slower and failing to catch up with their higher-income counterparts. For example, while *Pest* and *Győr-Moson-*Sopron—sub-regions of the high-income capital and Western Transdanubia regions—are growing faster despite their higher initial per capita GDP, relatively poorer regions in the south (e.g., *Somogy, Tolna,* Bács-Kiskun) and the north (e.g., *Heves, Borsod-Abaúj-Zemplén, Jász-Nagykun-Szolnok*) are falling behind.

**Table 1. Hungary: Beta Convergence: Panel Regression Estimates**

| | Model 1 | Model 2 |
|---|---|---|
| $y_{r,t-1}$ | -0.100* [0.0542] | -1.113*** [0.0789] |
| $y_{r,t-1}$ * (*regional dummy*) | | |
| Pest | | -0.165*** [0.0247] |
| Fejér | | 0.190*** [0.0283] |
| Komárom-Esztergom | | -0.0951*** [0.0246] |
| Veszprém | | 0.0774 [0.0893] |
| Györ-Moson-Sopron | | 0.0908*** [0.0275] |
| Vas | | -0.304*** [0.0344] |
| Zala | | -0.140*** [0.0476] |
| Baranya | | -0.0731 [0.0828] |
| Somogy | | 0.199* [0.0958] |
| Tolna | | 0.401*** [0.0489] |
| Borsod-Abaúj-Zemplén | | 0.129*** [0.0202] |
| Heves | | 0.334*** [0.0407] |
| Nógrád | | -0.0296 [0.0887] |
| Hajdú-Bihar | | -0.0491 [0.0640] |
| Jász-Nagykun-Szolnok | | 0.251*** [0.0371] |
| Szabolcs-Szatmár-Bereg | | 0.354*** [0.0635] |
| Bács-Kiskun | | 0.542*** [0.0216] |
| Békés | | 0.0739 [0.0845] |
| Csongrád-Csanád | | 0.0701 [0.0749] |
| Constant | 1.158** [0.523] | 10.05*** [1.084] |
| Observations | 320 | 320 |
| $R^2$ | 0.593 | 0.895 |
| Time fixed-effects | Y | Y |
| Regional fixed-effects | N | Y |

Sources: Eurostat, OECD, and IMF staff calculations.
Note: Robust standard errors shown in square brackets.
Statistical significance at the following levels: *** = 1%, ** = 5%, * = 10%

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[3] A related concept is $\sigma$-convergence, which examines whether regional per capita income dispersion decreases over time, indicating poorer regions are catching up (Kremer et al., 2021). Both beta and sigma convergence are essential to assess the quality of convergence, as faster growth in lower-income regions alone does not ensure a reduction in income dispersion.

**8.      A standard decomposition is adopted to pin down the drivers of regional disparities.**
The results analyzed above show that regional income convergence dynamics have been mixed.
However, different growth components (e.g., labor productivity, labor force participation rates) may
play different roles in different regions. To discipline the analysis on the search of the drivers
underpinning regional income disparities, a standard growth decomposition framework—à la
Balakrishnan and others (2022)—is employed as summarized below:

$$y_{pc} = \frac{GDP}{Pop} = \frac{GDP}{Emp} \times \frac{Emp}{LF} \times \frac{LF}{WorkAgePop} \times \frac{WorkAgePop}{Pop} \qquad (2)$$

where GDP per worker $\left(\frac{GDP}{Emp}\right)$ represents labor productivity, employment to labor force ratio $\left(\frac{Emp}{LF}\right)$

indicates labor utilization, while the labor force participation rate and working age share are
represented by the last two terms.  Convergence (or divergence) in each growth component is then
empirically examined, one at a time, using Equation 1 with region and time fixed effects.

**9.      Divergence in productivity and labor force participation have been the key drivers of
regional income disparities in Hungary over the last two decades**. The results show strong
divergence in labor productivity and labor force participation (Figure 3, left panel) while
convergence is observed in the other two factors—working age share and labor utilization. The large
and statistically significant labor productivity beta estimates clearly point to the outsized role of
productivity differentials in underpinning regional income disparities in Hungary (European
Commission, 2023). That is, while regions enjoying high initial productivity and labor force
participation rates are improving faster on these indicators, those with lower initial conditions are
falling behind (Figure 3, right panel).

**Figure 3. Drivers of Regional Income Convergence and Divergence**



**Beta Convergence and Divergence in Growth Components**
(Percent)

Sources: Eurostat; OECD; and IMF staff calculations.
Note: Error bars show 90% confidence interval; positive values indicate increased disparities. Estimates are
based on a regional (NUTS 3) beta convergence framework, regressing the growth of each variable on its
initial level, time, and region fixed effects.

**Beta Convergence and Divergence in Labor Productivity**
(Percent)

Sources: OECD; and IMF staff calculations.
Note: Coefficient estimates from regressing regional labor productivity growth on its initial level interacted
with regional dummies, including region-time fixed effects. Error bars show 90% confidence interval.

**10.** **However, there is strong heterogeneity in labor productivity convergence and divergence patterns across thriving versus lagging regions**, with some lagging NUTS 3 regions in

the north (e.g., HU331—*Bács-Kiskun*) gradually catching up with relatively higher-income and more productive regions (e.g., HU120—*Pest*). Despite their low productivity, the results (Figure 4) suggest that lagging Hungarian regions[4] tend to have higher employment shares in industry, (and manufacturing subsector), contrary to trends observed in other emerging markets and advanced economies (IMF, 2019). This result possibly points to the low value-added nature of regional industrial activity in Hungary as well as the uncompetitive structure of SMEs financing amid strong dependence on public subsidies (European Commission, 2023). Like trends elsewhere, these lagging regio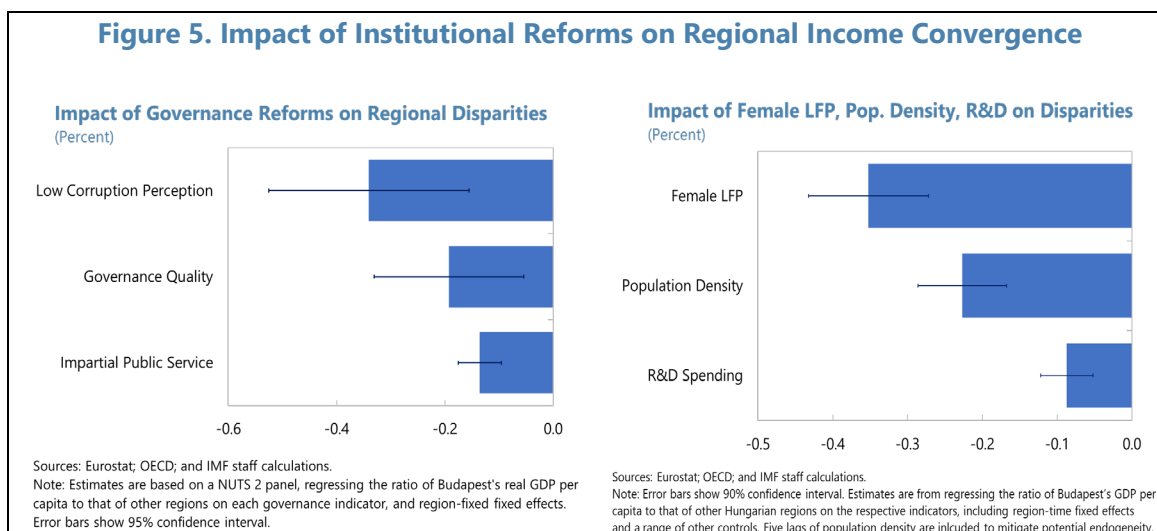ns tend to have higher employment concentration in agriculture but lower in high productivity services (e.g., professional business services, real estate, finance & insurance, ICT) than other regions.



**Figure 4. Sectoral Employment Shares: Lagging vs. Other Regions**

(Percentage point difference)

Sources: Eurostat; OECD regional database; and IMF staff calculations.
Note: Error bars show 90% confidence interval. Lagging regions are defined as those with real GDP per capita below the national regional median in 2000-19 and with average growth below the country's average over 2000-19. Coefficient estimates are from regressing the mean-normalized difference between respective employment shares in lagging vs other regions.

**11.** **The role of strong institutions, proxied by good governance, is also examined.** The decomposition framework (Equation 2) employed above does not directly include several other factors that drive growth, especially institutions. Using good governance as a proxy for institutional quality, Equation 1 is re-estimated with the ratio of Budapest's per capita income to the income of other NUTS 2 (or 3) regions on the respective reform indicators as the dependent variable. This is regressed on selected governance reform indicators from the European Quality of Governance database,[5] with region-time fixed effects and a range of other controls included. The results, presented in Figure 5 (left panel), suggest that good governance (i.e., low corruption perception, quality institutions, and impartial public service deliver) has a statistically significant effect in reducing disparities and promoting regional income convergence. These results are consistent with findings in the literature that closing governance gaps can promote a conducive business climate, thus incentivizing private investment and facilitating economic diversification (Budina and others, 2023).

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[4] Lagging regions are defined as those with real GDP per capita below the national regional median in 2000 and with average growth below the country's average over 2000–19.

[5] These are NUTS 2 (rather than national) governance indicators (see Charron and others, 2024). With overall governance reforms centered at the national level, these indicators reflect local institutional capacity.

**Figure 5. Impact of Institutional Reforms on Regional Income Convergence**

**Impact of Governance Reforms on Regional Disparities**
(Percent)

Sources: Eurostat; OECD; and IMF staff calculations.
Note: Estimates are based on a NUTS 2 panel, regressing the ratio of Budapest's real GDP per capita to that of other regions on each governance indicator, and region-fixed fixed effects. Error bars show 95% confidence interval.

**Impact of Female LFP, Pop. Density, R&D on Disparities**
(Percent)

Sources: Eurostat; OECD; and IMF staff calculations.
Note: Error bars show 90% confidence interval. Estimates are from regressing the ratio of Budapest's GDP per capita to that of other Hungarian regions on the respective indicators, including region-time fixed effects and a range of other controls. Five lags of population density are incuded to mitigate potential endogeneity.

**12.      Institutional reforms aimed at increasing female LFP, migration, and R&D investment can also help speed up regional income convergence**. The results (in Figure 5, right panel) also reveal that increasing female labor force participation and population density can promote regional income convergence, consistent with the adverse impact that regional LFP differentials have on convergence (Figure 3, left panel). Increasing spatial density, including via incentivized inter and intra-regional labor mobility, can attract investments and promote efficiency in regional economies (Krugman, 1991). Such increased investments, particularly when directed to R&D, can promote regional dynamism amid structural transformations (Budina and others, 2023) like the ongoing digital and green transitions.

## C.   Regional Disparities Through the Lens of the Twin Digital and Green Transitions

**13.      The Hungarian economy, like elsewhere in Europe and globally, is undergoing the twin digital and green transitions**, requiring structural adjustments that vary by region due to differing economic structures and specializations. Absent targeted policy interventions, regional disparities may deepen as higher-income regions exploit their high knowledge- and green-intensity (Figure 2) to thrive while poorer regions lag (OECD, 2023; Maucorps and others, 2023). With a focus on how the labor market effects of these transitions could affect regional disparities, this section proceeds in two steps. First, it assesses Hungary's digital preparedness—relative to the EU—and examines how sub-national differences in digital access and skills could widen existing productivity gaps. Second, it summarizes the regional concentration of 'green jobs' and explores the association between labor market greenness, knowledge intensity, and regional income levels.

### Digital Transition

**14.      Hungary risks missing out on the gains from AI and related digital technologies.** As analyzed in the previous section, productivity differences have contributed to Hungary's persistent regional disparities and slow income convergence (Figure 3, left panel). Drawing on recent IMF research on generative AI and the future of work (see Cazzaniga and others, 2024; Pizzinelli and
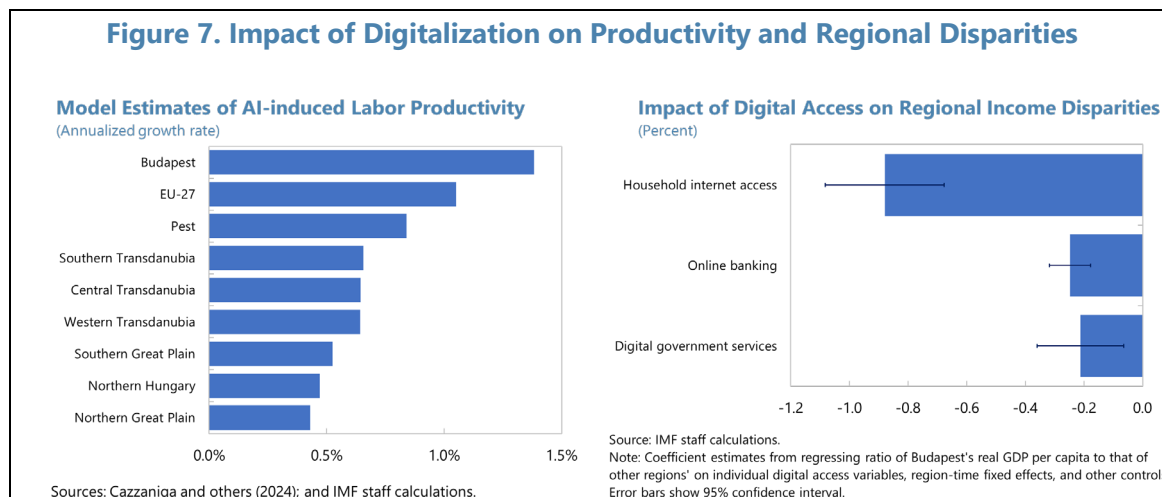
others, 2023), this section examines how the rapid emergence of AI could deepen existing regional digital access and skill gaps, thus widening the rural-urban productivity gap. Figure 5 puts Hungary's AI exposure and preparedness[6] into context with the EU, showing that despite being relatively less exposed (below regional AI exposure median) to AI-related labor market disruptions, Hungary is largely underprepared to integrate and harness the potential benefits of AI technologies. Active labor market policies and flexibility, coupled with strong legal frameworks are critical for facilitating AI-induced labor market transitions in Hungary (see Cazzaniga and others, 2024).



**Figure 6. AI Exposure and Preparedness**
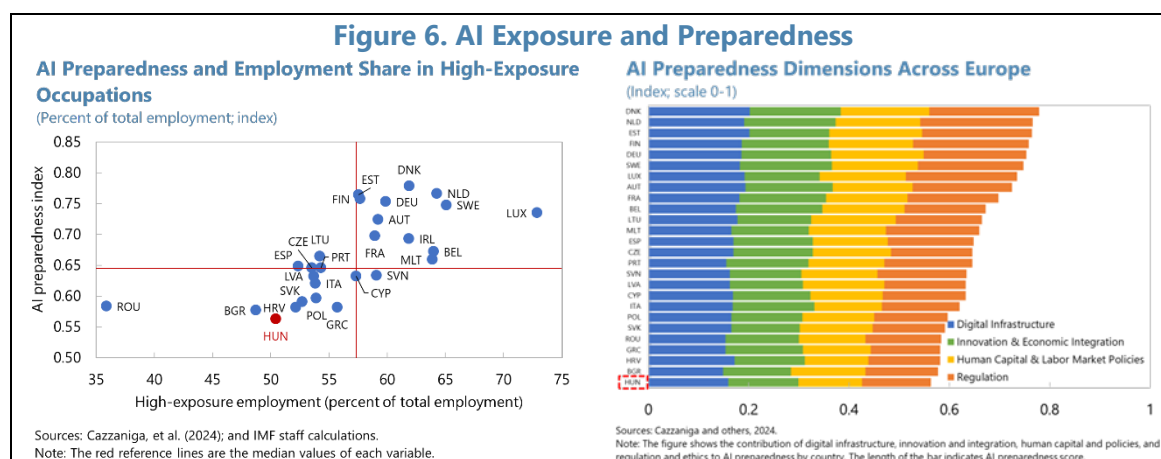
**15.**      **Model results point to AI-induced widening in regional labor productivity gaps.** To assess AI's economic impact on productivity, Cazzaniga and others (2024) employed a Cobb-Douglas aggregated task-based model—à la Acemoglu and Restrepo (2022)—that integrates several key factors, including differences in labor productivity, asset holdings, AI exposure, and the complementarity between human labor and AI. The model is calibrated to Hungary, specifically linking the productivity effects of AI[7] to the share of digitally skilled labor force in each region. The results suggest that thriving regions are likely to enjoy higher productivity gains, potentially widening regional income disparities (Figure 7, left panel). But increased investment in digital infrastructure (e.g., internet access and digitized public services) can help narrow the income gap (Figure 5, right panel).

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[6] The IMF AI Preparedness Index, constructed by Cazzaniga and others (2024), is now a standard IMF indicator, available in Datamapper: https://www.imf.org/external/datamapper/datasets/AIPI

[7] With AI technologies still being developed and adoption currently at low levels in many economies, particularly at sub-national levels, model-based estimates of AI-induced productivity are highly stylized and should be interpreted with caution (see Acemoglu, 2024).

**Figure 7. Impact of Digitalization on Productivity and Regional Disparities**

**Model Estimates of AI-induced Labor Productivity**
(Annualized growth rate)



Sources: Cazzaniga and others (2024); and IMF staff calculations.

**Impact of Digital Access on Regional Income Disparities**
(Percent)



Source: IMF staff calculations.
Note: Coefficient estimates from regressing ratio of Budapest's real GDP per capita to that of other regions' on individual digital access variables, region-time fixed effects, and other controls. Error bars show 95% confidence interval.

**Green Transition**

**16.     The green transition may also deepen disparities, especially through regional differences in labor market outcomes.** Like the digital transition, the local effects of national green policies tend to differ across regions, often depending on regional heterogeneity in carbon intens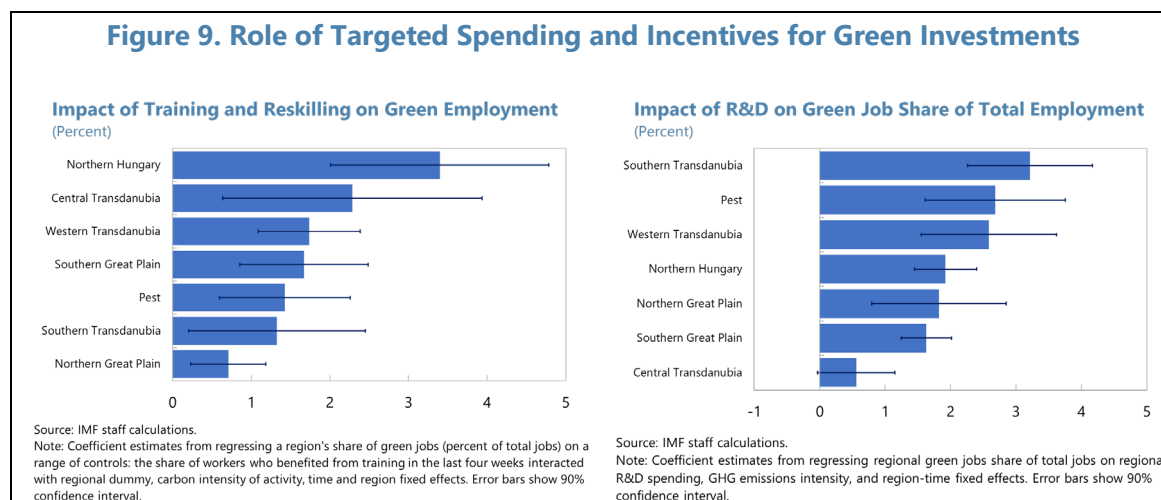ity of activity and employment. In Hungary, like elsewhere in Europe, the green share of total employment tends to be larger in higher-income regions (Figure 6, left panel). Similarly, the greenness of labor markets is positively correlated with educational attainment (Figure 6, right panel), consistent with evidence in the literature that green-intensive jobs provide wage premium (Bergant and others, 2022) largely owing to their higher skill requirement. These trends position higher-income regions to thrive in the transition to carbon neutrality, potentially widening regional income disparities (Maucorps and others, 2023).

**Figure 8. Green Job Composition of Regional Labor Markets**

**Correlation Between Green Jobs and Regional Income**
(Log of each variable)



Sources: European Commission: EU RCES Database; and IMF staff calculations.

**Correlation Between Green Jobs and Education Attainment**
(Log of each variable)



Sources: European Commission: EU RCES Database; Eurostat; and IMF staff calculations.
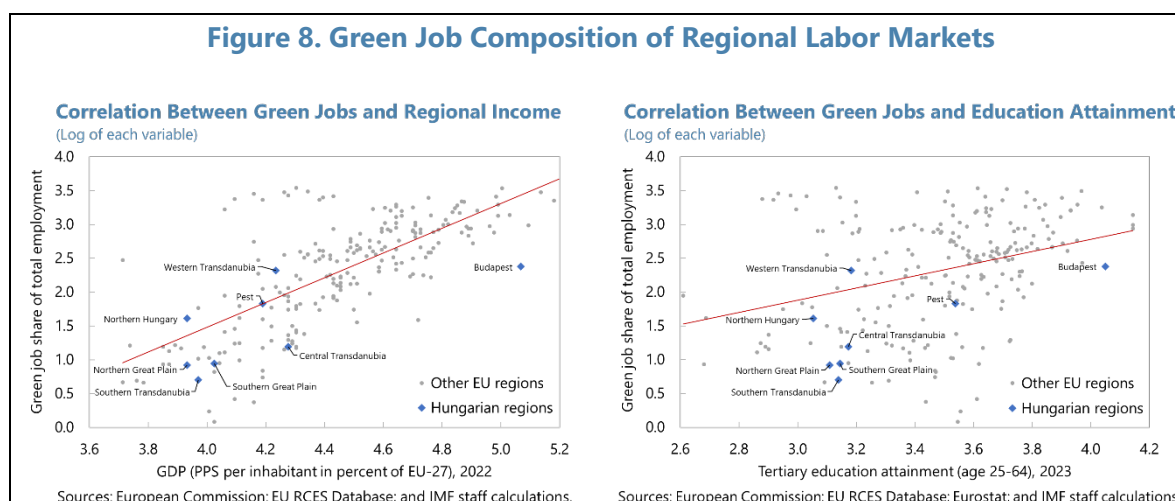
**17.     Targeted spending and incentives for green investments can help green regional labor markets**. The extent to which the green transition deepen structural gaps in regional labor markets depends on how policies are designed and targeted, emphasizing the need for reskilling workers to transition to greener opportunities and incentivizing green R&D investments. To examine the impact

of these policies on green employment, the green job share of total employment in each Hungarian region is regressed on a range of controls, including the share of workers benefiting from training and R&D spending as separate independent variables. The results (in Figure 7) suggest that training, including in the form of reskilling, can reduce disparities in green employment. Prioritizing and incentivizing private R&D investment can also have similar positive effect.

**Figure 9. Role of Targeted Spending and Incentives for Green Investments**

**Impact of Training and Reskilling on Green Employment**
(Percent)

**Impact of R&D on Green Job Share of Total Employment**
(Percent)

Source: IMF staff calculations.
Note: Coefficient estimates from regressing a region's share of green jobs (percent of total jobs) on a range of controls: the share of workers who benefited from training in the last four weeks interacted with regional dummy, carbon intensity of activity, time and region fixed effects. Error bars show 90% confidence interval.

Source: IMF staff calculations.
Note: Coefficient estimates from regressing regional green jobs share of total jobs on regional R&D spending, GHG emissions intensity, and region-time fixed effects. Error bars show 90% confidence interval.

## D. Conclusion

**18.      Hungary's convergence to the average EU income level is underway, but at a slow and uneven pace amid persistently high regional disparities**. Hungary has experienced significant economic growth over the past decades, with per capita income approaching the EU average. This growth, however, has not been evenly distributed across the country, leading to pronounced regional disparities. Budapest and its surrounding areas have surged ahead, benefiting from higher levels of investment, better infrastructure, and greater access to global markets. In contrast, many rural and less developed regions have lagged, characterized by low productivity and higher unemployment rates.

**19.      The ongoing twin digital and green transitions could worsen these disparities.** They present both opportunities and challenges for regional development in Hungary. On the one hand, these transitions offer the potential for creating new jobs, fostering innovation, and promoting sustainable development. On the other hand, they risk exacerbating existing regional disparities without targeted interventions. Budapest and other thriving regions are better positioned to capitalize on the emerging opportunities, while lagging regions risk falling further behind amid lower levels of digital readiness and concentration of employment in carbon-intensive, low-value added sectors. Investment toward reskilling workers and incentives for green R&D can play a vital in closing the urban-rural income and green employment gaps.

**20.      Deeper, targeted reforms are needed to facilitate a balanced and sustainable income convergence path.** To ensure that the benefits of economic growth and the digital and green transitions are more evenly distributed, targeted policy interventions are essential. These could include investing in digital infrastructure and education in lagging regions and providing incentives for green private investments. Good governance, including at the regional level (anti-corruption, regulatory quality of public institutions) can promote dynamism and growth in regional economies.

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