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How Does Immigration Affect Labor Productivity? Time-Series Evidence from Germany with Innovation as a Mediating Channel

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ABSTRACT

This paper investigates the impact of immigrants on labor productivity in Germany and their effect on innovation. The study relies on the World Bank's World Development Indicators (WDI) and combines four indicators of innovation output and input (R&D expenditure, researchers in R&D, resident patent applications, and scientific and technical journal articles) into a single composite Innovation Index using principal component analysis (PCA). The index captures 84.5% of the common variance among the indicators, with 2001-2021 serving as the core estimation window for annual national time-series data for Germany. Net migration is used to capture the level of immigration in the Baron and Kenny (1986) mediation model, supplemented by a Sobel test of the indirect effect. The model includes the following control variables: gross capital formation, trade openness, and foreign direct investment.

The results indicate that net migration is a significant positive predictor of the Innovation Index (a-path, p = 0.039). In turn, the Innovation Index is a significant positive predictor of labor productivity (b-path, p = 0.036), supporting the existence of an innovation-mediated channel. The indirect effect of migration on productivity is positive but weak (Sobel z = 1.60, p = 0.110), and the mediation effect, considered as an indirect relationship between the two variables, is not statistically significant. This finding is consistent with the mediation literature, where indirect effects may be weak or may only exist in one direction.

Compared with the limited evidence available from shorter time-series studies, these results provide more substantive, although still preliminary, support for the innovation-mediation hypothesis. However, several important limitations remain: the analysis is conducted at the national level; net migration is not disaggregated by skill level; and the sample size is relatively small for conventional econometric applications (n = 21 for the full model). The paper places these findings within the context of the international literature on skilled migration, innovation, and productivity. It also explores policy developments in Germany regarding skilled immigration and provides directions for future research using regionally disaggregated and skill-disaggregated migration data.

Keywords: high-skilled immigration; labor productivity; innovation; mediation analysis; principal component analysis (PCA); Germany; net migration

INTRODUCTION

Labor productivity growth is a crucial factor for Germany's future economic competitiveness and is influenced by the size and quality of the workforce, the pace of technological progress, and the amount of capital available to workers. With a shrinking working-age population and a long-standing shortage of skilled labor, Germany has increasingly relaxed its immigration regulations for skilled workers, culminating in the Skilled Immigration Act (Fachkräfteeinwanderungsgesetz – FEG) in 2020 and its significant amendment in November 2023. These reforms reduced salary thresholds in the EU Blue Card program, expanded the definition of shortage occupations, and introduced a points-based "Opportunity Card" for job seekers. They reflect a policy expectation that by lowering barriers to immigration and attracting specific groups of workers, high-skilled immigration can help offset demographic decline and support continued productivity growth.

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The relationship between immigration and labour productivity is not automatic or uncontested. A broad body of international literature has identified several potential benefits of skilled immigrant workers, including an expanded human-capital pool, an increased supply of STEM (science, technology, engineering, and mathematics) workers, and a disproportionate contribution to patenting and innovation. Among these channels, innovation has received particular attention, as skilled immigrants may contribute not only directly through their own labor input but also indirectly through the creation of ideas, patents, and research outputs that improve productivity across the economy.

This paper empirically examines this question for Germany: Is high-skilled immigration associated with labor productivity, and does this relationship operate through innovation? The analysis uses annual national indicators for Germany from the World Bank's World Development Indicators (WDI) database, covering the period from 2001 to 2025. Ten core series are used, including GDP per person employed (the productivity outcome); net migration and the proportion of the labor force with advanced education (immigration-related variables); resident patent applications, R&D expenditure, researchers in R&D, and scientific and technical journal articles (innovation indicators, combined into a single Innovation Index using principal component analysis); and gross capital formation, trade openness, and foreign direct investment inflows (control variables). International migrant stock as a percentage of the population is reported descriptively but excluded from the regression analysis because the World Bank provides this indicator only every five years for Germany, making it unsuitable for annual time-series estimation.

An important methodological improvement of this paper, compared with a preliminary exploratory version based on a shorter period of 2016-2024, is the use of a longer estimation window (2001–2021, with 21 annual observations in the full model) and a formal Baron-and-Kenny-style mediation framework supported by a Sobel test of the indirect effect, rather than only descriptive correlation analysis. The extended time period and larger sample allow the study to test, rather than simply describe, whether innovation mediates the relationship between migration and productivity in Germany's national time series. However, the study also has important limitations from the beginning: it is a national-level time-series analysis for Germany rather than a state-level (Bundesländer) analysis, and net migration is a broad flow indicator that does not distinguish immigrants by skill level. These limitations are treated as constraints of the study rather than strengths.

The remainder of the paper is organized as follows. Section 2 reviews the theoretical and empirical literature on immigration, innovation, and productivity, with a focus on the German and European context. Section 3 presents the data, the construction of the Innovation Index, and the mediation model specification. Section 4 reports the descriptive, correlational, and mediation-regression results. Section 5 discusses the findings in relation to the existing literature. Section 6 addresses the limitations, and Section 7 concludes with policy implications and directions for future research. Figure 1, at the end of this section, situates the innovation-mediation pathway tested in this paper within the broader set of channels through which immigration can affect productivity that are reviewed in Section 2.

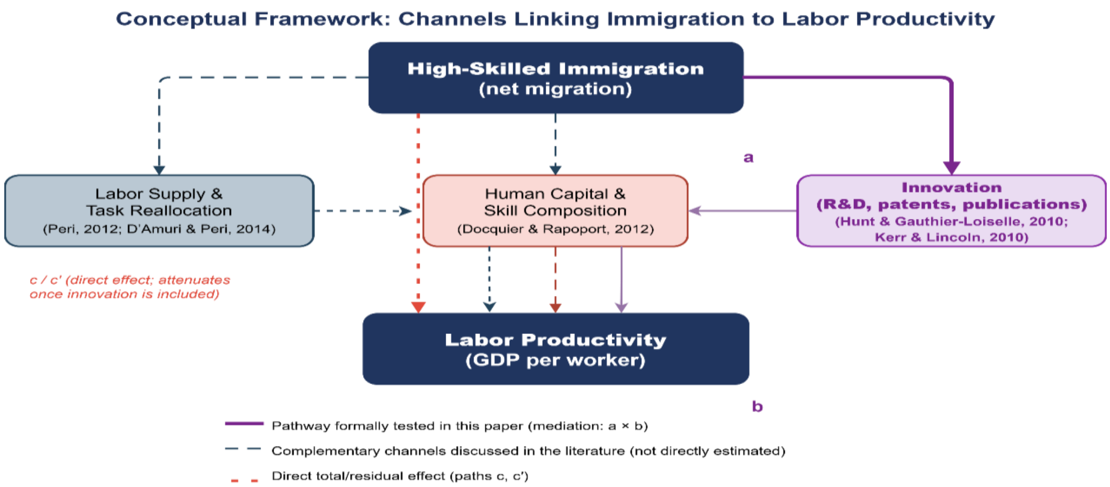

Figure 1. Conceptual Framework: Channels Linking Immigration to Labor Productivity. Note: the solid highlighted path (Migration → Innovation → Productivity) is the mediation pathway formally estimated in

Sections 3–4 of this paper; the dashed channels summarize complementary mechanisms discussed in Section 2 but not directly estimated here.

LITERATURE REVIEW

Immigration and Labor Productivity

Most of this literature starts from the premise that immigrants and native workers are often imperfect complements in production and tend to perform different tasks based on comparative advantage (D'Amuri & Peri, 2014). Immigration does not necessarily replace native workers; instead, it may encourage a reallocation of native labor toward more complex tasks requiring greater communication skills, ultimately improving labor-market efficiency. Using state-level immigration data from 1981 to 2010, Peri (2012) showed that an increase in immigration was associated with higher total factor productivity (TFP), without causing a corresponding decline in native employment. He found that a one-percent increase in employment associated with immigration was linked to a 0.4 to 0.5 percent increase in income per worker, which he attributed to more efficient task specialization and immigration's influence on the skill bias and capital intensity of production methods.

Alesina, Harnoss, and Rapoport (2016) showed that, at the national level, the composition of a country's immigrant population is positively associated with economic well-being, particularly when immigrant populations are diverse rather than simply large. This effect is particularly pronounced for skilled immigrants in high-income host countries. D'Amuri and Peri (2014) examined fourteen Western European countries before and during the Great Recession and found that immigration was associated with an increase in the occupational complexity of jobs performed by native workers. This effect was stronger in countries with more flexible labor-market institutions. The literature suggests that although the direction of immigration's effect on productivity may be similar across countries, the magnitude of this effect may be more limited in Germany due to its relatively regulated labor market compared with more flexible economies. This pattern is echoed in broader syntheses of the high-skilled migration literature, which similarly emphasize that destination-country effects depend on the composition and absorptive capacity of the host economy rather than on migrant numbers alone (Docquier & Rapoport, 2012; Kerr, Kerr, Özden, & Parsons, 2016).

Innovation as a Mediating Channel

A recent systematic review and meta-analysis of this literature concludes that the immigration–innovation relationship is among the more robust and widely replicated findings in migration economics, even though effect sizes vary with country context and how innovation is measured (Capoani, Chabert, & Izzo, 2024). An alternative and complementary body of literature focuses on a specific innovation pathway through which skilled immigration may influence productivity. Hunt and Gauthier-Loiselle (2010) used a panel of U.S. states from 1940 to 2000 and found that a one-percent increase in the immigrant college graduate population was associated with an approximately 9–18 percent increase in patents per capita. They attributed this effect to immigrants' overrepresentation in science and engineering fields. Using changes in the H-1B visa cap, Kerr and Lincoln (2010) showed that the supply of high-skilled immigrants had a significant positive effect on invention by ethnic inventors in cities and firms that relied heavily on the program, with little evidence of displacement of domestic inventors. More recent micro-level evidence reinforces this pattern at the individual level: tracking inventors who relocated internationally, Pellegrino, Penner, Piguet, and de Rassenfosse (2023) found that patenting output rose by roughly 30 percent following migration, consistent with a causal channel rather than a purely compositional one.

These findings are complemented by a smaller European and Germany-specific literature. Niebuhr (2010) examined a cross-section of German regions and found that cultural diversity within regional workforces was positively associated with patent applications, suggesting that immigration-related diversity can promote local knowledge spillovers. This study is among the few to analyze the innovation channel using sub-national German data and highlights the importance of state-level (Bundesländer) evidence for directly testing the hypothesis presented in this paper. This finding is corroborated by Ozgen, Nijkamp, and Poot (2013), who used Dutch firm-level micro-data and likewise found that greater workforce cultural diversity was associated with higher firm-

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level innovation propensity, indicating that the sub-national European evidence points in the same direction as the German regional evidence.

The conceptual link between high-skilled immigration, innovation, and productivity can be summarized as follows: an increase in the supply of researchers, engineers, and specialized human capital contributes to greater idea generation, patenting activity, and R&D intensity. These improvements in innovation capacity can then increase total factor productivity (TFP) and ultimately enhance labor productivity. A regression-based mediation approach, which separates a total effect into direct and indirect (mediated) effects, is commonly based on Baron and Kenny's (1986) framework, later developed further through the Sobel (1982) test of the indirect effect and modern bootstrap-based methods. This study provides a formal mediation analysis made possible by the longer estimation window from 2001 to 2021 used in the present paper (Section 3), compared with an earlier exploratory version based on the shorter 2016–2024 period. Methodologists have since noted that the classic Baron-Kenny approach and the Sobel test can have lower statistical power than modern bootstrap-based resampling methods, particularly in small samples (Preacher & Hayes, 2008; Zhao, Lynch, & Chen, 2010); this study follows the Baron-Kenny/Sobel framework for comparability with the exploratory phase of this project while flagging this power limitation explicitly in Sections 3.4 and 6.

The German Context

Answering this question is highly policy-relevant because Germany faces a significant demographic challenge, and its recent policy response has been deliberate. Facing a shrinking working-age population and a severe shortage of skilled workers across engineering, information technology, healthcare, and skilled trades, the German government introduced the Skilled Immigration Act in March 2020 and significantly revised it in November 2023. The reforms reduced EU Blue Card minimum salary requirements, expanded the range of eligible shortage occupations, and introduced a three-pillar immigration system based on skilled labor, experience, and potential, alongside a job-search Opportunity Card. These reforms were explicitly justified as a productivity-oriented response to labor shortages, making Germany a relevant case for examining whether changes in immigration flows are associated with trends in productivity and innovation.

At the same time, Germany's high-technology export sector, well-established R&D infrastructure (including the Fraunhofer and Max Planck research networks), and large manufacturing base indicate that migration is only one factor influencing innovation inputs and outputs. Other important factors include energy costs, global demand for German capital goods, and domestic industrial policy. Therefore, any relationship observed between migration and productivity or innovation indicators in Germany's aggregate data must be interpreted while considering these broader influences, which will be discussed further in Sections 5 and 6.

Table 1 summarizes the principal studies reviewed above, organized by geographic and data context, empirical method, and headline finding, and situates the present paper relative to this literature.

Table 1. Summary of Key Studies on Immigration, Innovation, and Productivity

Peri (2012)	U.S. states, 1960–2010	State panel; IV for immigrant employment share	+1% immigration-driven employment growth → +0.4–0.5% income per worker via task specialization and skill/capital-intensity effects; no native displacement
D'Amuri & Peri (2014)	14 Western European countries, pre/post Great Recession	Country panel; occupational task-complexity index	Immigration raises the occupational complexity of native-held jobs; effect stronger where labor markets are more flexible

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Alesina, Harnoss, & Rapoport (2016)	Cross-country, c. 1990–2000	Cross-sectional regression; birthplace-diversity index	Diversity (not just size) of the skilled immigrant population is positively associated with income and TFP in high-income host countries
Hunt & Gauthier-Loiselle (2010)	U.S. states, 1940–2000	State panel; instrumental variables	+1% immigrant college-graduate population share → +9–18% patents per capita
Kerr & Lincoln (2010)	U.S. cities/firms, H-1B visa cap changes	Panel; policy-driven instrument	H-1B admissions raise ethnic invention with little displacement of native inventors
Pellegrino, Penner, Piguet, & de Rassenfosse (2023)	Matched international inventors, multi-country	Individual-level panel; inventor fixed effects	Patenting output rises by roughly 30% after an inventor relocates internationally
Niebuhr (2010)	German regions, cross-section	Regional cross-section; knowledge-production function	Cultural diversity within regional workforces positively associated with regional patent applications
Ozgen, Nijkamp, & Poot (2013)	Dutch firms, micro-data	Firm-level regression	Greater workforce cultural diversity raises firm-level innovation propensity
Capoani, Chabert, & Izzo (2024)	Cross-study evidence base	Systematic review & meta-analysis	Immigration–innovation relationship is robust and widely replicated; effect sizes vary with country context and measurement approach
Docquier & Rapoport (2012)	Cross-country review	Literature synthesis	Skilled-migration effects on origin and destination economies depend on diaspora externalities, remittances, and return migration, not on migration volume alone
This paper	Germany, 2001–2021 (national, annual)	Baron & Kenny (1986) mediation model + PCA-based Innovation Index + Sobel (1982) test	Net migration significantly predicts the Innovation Index (a-path); the Innovation Index significantly predicts productivity (b-path); indirect effect positive but only marginally significant (Sobel p = 0.110)

DATA AND METHODOLOGY

Data Source and Variables

The data that has been utilized for this study have been derived from the WDI database of the World Bank and have been selected for Germany, ranging from 2001 to 2025 on an annual basis. Eleven variables have been selected and are described in Table 2 below.

Table 2. Variables Used in the Analysis

Variable	WDI Code	Role	Years

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GDP per person employed (const. 2021 PPP $)	SL.GDP.PCAP.EM.KD	Dependent variable: labor productivity	2001–2025
Net migration	SM.POP.NETM	Independent variable: immigration (flow)	2001–2025
Labor force with advanced education (%)	SL.TLF.ADVN. ZS	Supplementary: workforce skill composition	2001–2024
Patent applications, residents	IP.PAT.RESD	Innovation input to PCA index	2001–2021
R&D expenditure (% of GDP)	GB.XPD.RSDV.GD.ZS	Innovation input to PCA index	2001–2023
Researchers in R&D (per million people)	SP.POP.SCIE. RD. P6	Innovation input to PCA index	2001–2023
Scientific and technical journal articles	IP.JRN.ARTC.SC	Innovation input to PCA index	2001–2023
Gross capital formation (% of GDP)	NE.GDI.TOTL. ZS	Control: physical capital investment	2001–2025
Trade (% of GDP)	NE.TRD.GNFS. ZS	Control: trade openness	2001–2025
Foreign direct investment, net inflows (% of GDP)	BX.KLT.DINV.WD.GD.ZS	Control: foreign capital/technology transfer	2001–2025
International migrant stock (% of population)	SM.POP.TOTL. ZS	Descriptive only (excluded from regression)	5 pts: 2005–2024

Table 3. Data Sources

Indicator Group	**WDI Series Code(s)**	**Primary Compiling Agency (via WDI)**	**Coverage Used**
Labor productivity; capital formation; trade openness	SL.GDP.PCAP.EM.KD; NE.GDI.TOTL.ZS; NE.TRD.GNFS.ZS	National statistical offices; OECD National Accounts; World Bank staff estimates	2001–2025
Foreign direct investment, net inflows	BX.KLT.DINV.WD.GD.ZS	IMF International Financial Statistics & Balance of Payments; World Bank/OECD GDP estimates	2001–2025
Net migration; international migrant stock	SM.POP.NETM; SM.POP.TOTL.ZS	United Nations Population Division, World Population Prospects / International Migrant Stock	2001–2025 (stock: 2005, 2010, 2015, 2020, 2024)
R&D expenditure; researchers in R&D	GB.XPD.RSDV.GD.ZS; SP.POP.SCIE.RD.P6	UNESCO Institute for Statistics (UIS)	2001–2023
Resident patent applications	IP.PAT.RESD	World Intellectual Property Organization (WIPO), Patent Report: Statistics on Worldwide Patent Activity	2001–2021

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Scientific and technical journal articles	IP.JRN.ARTC.SC	U.S. National Science Foundation, Science & Engineering Indicators	2001–2023
Labor force with advanced education	SL.TLF.ADVN.ZS	International Labour Organization, ILOSTAT / Education and Mismatch Indicators database	2001–2024

All series were retrieved from the World Bank's World Development Indicators (WDI) database (World Bank, 2025), https://databank.worldbank.org/. The World Bank compiles and redistributes these indicators; the agencies listed above are the primary sources credited in the WDI series metadata. See Table 2 for the WDI series code, analytical role, and years used for each variable.

As in the studies of Peri (2012) and related research, net migration is used as the primary indicator of immigration. As in the initial exploratory phase of this project, it is important to clarify that the WDI net migration series is not disaggregated by skill level. It captures all cross-border population flows, including but not limited to labor migration under skilled-worker visa schemes such as the EU Blue Card. The share of the labor force with advanced education is included as a supplementary descriptive and correlational variable representing the overall skill composition of the German workforce. However, it is a national workforce characteristic rather than an immigrant-specific measure and is therefore not used as the main regressor. International migrant stock (% of population), while conceptually the most direct available measure of the accumulated migrant population, is reported by the World Bank for Germany only at five-year intervals (2005, 2010, 2015, 2020, and 2024). Therefore, it is excluded from the regression and correlation analyses and is reported descriptively only in Section 4.1.

The innovation channel is represented by four indicators: R&D expenditure, researchers in R&D, resident patent applications, and scientific and technical journal articles. Since including all four indicators separately in the mediation regression would consume too many degrees of freedom given the available sample size, they are combined into a single composite Innovation Index using principal component analysis (PCA), as described in Section 3.2. Gross capital formation, trade openness, and FDI net inflows are included as standard control variables representing physical capital investment, trade exposure, and foreign capital and technology transfer, respectively.

Construction of the Innovation Index via PCA

The four innovation indicators were standardized with a mean of zero and scaled to unit variance and analyzed using principal component analysis (PCA) over the 2001–2021 period ($n = 21$), during which all four indicators are available without missing values. The first principal component (PC1) explains 84.5% of the total variance among the four standardized indicators, while the second principal component (PC2) explains an additional 13.4%. The remaining two components together account for less than 2% of the total variance. Following standard practices in the construction of composite indexes such as the Global Innovation Index (Dutta, Lanvin, Rivera León, & Wunsch-Vincent, 2024) and consistent with methodological guidance on composite-indicator construction (OECD/European Commission Joint Research Centre, 2008), the dominant share of common variation captured by PC1 allows it to be used as a single-dimensional Innovation Index for subsequent analysis.

Table 4 presents the PCA loadings of each input variable, showing the strength of the association between each indicator and the resulting index. R&D expenditure, researchers in R&D, and scientific articles all have positive and similar loadings (0.531, 0.536, and 0.516, respectively), suggesting that these indicators increased together over time, with higher levels contributing to higher values of the Innovation Index. Resident patent applications show a negative loading (−0.406), indicating that patent filings by German residents moved in the opposite direction during the same period, declining while R&D investment, researcher numbers, and publication output increased. This represents an important finding in itself and is discussed further in Sections 4 and 5. Rather than being a simple measure of "more innovation" in every sense, the constructed Innovation Index primarily reflects innovation input intensity and publication-based output, which was inversely related to resident patent filings during this specific period.

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Table 4. PCA Loadings on the First Principal Component (Innovation Index), 2001–2021 (n = 21)

Input Variable	PC1 Loading	Direction
R&D expenditure (% of GDP)	0.531	Positive
Researchers in R&D (per million)	0.536	Positive
Scientific and technical journal articles	0.516	Positive
Patent applications, residents	−0.406	Negative

PC1 explains 84.5% of total variance; PC2 explains 13.4%; PC3 and PC4 together explain <2%. Index oriented so that higher values indicate greater R&D/researcher/publication intensity.

Mediation Model Specification

The mediation hypothesis suggested in the title of the paper that innovation mediates the connection between skilled immigration and labor productivity is examined through the use of the traditional three-equation methodology proposed by Baron & Kenny (1986), with the additional Sobel (1982) test of the statistical significance of the indirect effect being carried out. All models are estimated using OLS estimation over the common 2001-2021 period (n = 21 years), when all variables and controls are present.

The total effect model (path c) runs productivity on net migration and all three controls, excluding the mediator:

$$Productivityt = c0 + c \cdot Migrationt + \beta^1 CapitalFormationt + \beta^2 Tradet + \beta^3 FDIt + \varepsilon t \qquad (1)$$

The mediator model (path a) regresses the Innovation Index on net migration, testing whether migration predicts innovation:

$$InnovationIndext = a0 + a \cdot Migrationt + \varepsilon t \qquad (2)$$

Model with mediator (b & c') regresses productivity on net migration and Innovation Index simultaneously, with all three control variables, to see if the Innovation Index is still explaining productivity after migration is taken into account, and if the effect of migration itself (c') becomes smaller compared to total effect (c):

$$Productivityt = c0' + c' \cdot Migrationt + b \cdot InnovationIndext + \beta^1 CapitalFormationt$$

$$+\beta^2 Tradet + \beta^3 FDIt + \varepsilon t \qquad (3)$$

The indirect (mediation) effect is evaluated as a product of regression coefficients a·b, and its statistical significance is checked using the Sobel (1982) test z-statistic ($z = (a \cdot b) / \sqrt{(b^2 SE_a^2 + a^2 SE^{b2})}$). Net migration is measured in units of 100,000 people. The choice of three controls is dictated by the necessity to conserve the degrees of freedom since in this specification we have n = 21 observations and six parameters to estimate (one constant, migration, the Innovation Index, and three controls, which gives 15 residual degrees of freedom in contrast to only 1–3 available during initial exploratory analysis for 2016-2024 period, but still low compared to conventional large sample requirements (at least 30-50 observations are needed).

Limitations of the Data and Method

The results presented in Section 4 should be interpreted in light of several limitations. First, the data are aggregated at the national level for Germany as a whole and do not provide a regional or state-level (Bundesländer) breakdown; therefore, they cannot support the type of cross-regional comparison used in sub-national studies such as Niebuhr (2010). Second, although the 2001–2021 estimation period (n = 21) represents a substantial improvement over the shorter sample considered previously, it remains relatively small. The Sobel test used in this study is conservative and sensitive to non-normality in small samples, meaning that the results should be viewed as suggestive rather than conclusive.

Third, the immigration measure used in this study is broader than the concept of "high-skilled immigration" stated in the paper's title. The net migration flow indicator provided by WDI does not distinguish immigrants by skill level, occupation, or visa category. This limitation is a direct consequence of the available WDI data and is discussed further in Section 6. Fourth, some predictors are correlated with each other and with time, creating a degree of multicollinearity in the full regression model (Section 4.4). Therefore, the coefficients of individual control variables should be interpreted with caution, even though the overall model fit is strong. Fifth, because the international migrant stock series is reported only at five-year intervals, it could not be included in any inferential analysis of migrant population size.

RESULTS

Descriptive Trends

Table 5 lists the initial and latest values available for each variable. German labor productivity increased by 11.4% over the given period, rising from $112,310 in 2001 to $125,086 in 2025, constant 2021 PPP. However, the increase was not continuous since labor productivity declined during both the financial crisis of 2009 and the year 2020. Net migration figures showed substantial volatility over the period, which moved from a positive number of 272,875 people in 2001 to a negative number of −334,072 people in 2025 after reaching a maximum of 981,552 in 2022 due to refugee flows associated with the Ukraine crisis (Brücker, Ehab, Jaschke, & Kosyakova, 2024).

Table 5. Descriptive Trends in Key Variables, Germany, 2001–2025

Variable	First Year	Last Year	Change
GDP per worker (const. 2021 PPP $)	112,310 (2001)	125,086 (2025)	+11.4%
Net migration (persons)	272,875 (2001)	−334,072 (2025)	Reversal (+ → −)
Labor force, advanced education (%)	75.94% (2001)	73.11% (2024)	−2.8 pp
Patent applications, residents	49,989 (2001)	39,822 (2021)	−20.3%
R&D expenditure (% of GDP)	2.38% (2001)	3.15% (2023)	+0.77 pp
Researchers in R&D (per million)	3,230 (2001)	5,926 (2023)	+83.5%
Scientific/technical journal articles	71,531 (2001)	108,782 (2023)	+52.1%
Gross capital formation (% of GDP)	22.76% (2001)	21.93% (2025)	−0.8 pp
Trade (% of GDP)	59.56% (2001)	78.51% (2025)	+18.9 pp
FDI, net inflows (% of GDP)	2.90% (2001)	1.88% (2025)	−1.0 pp

Source: World Bank WDI. Years vary by series due to differing reporting lags; see Table 2.

These four innovation input indices exhibit sharp divergence among themselves. The share of GDP spent on R&D increased from 2.38 to 3.15 percent, while R&D personnel increased by almost double (+83.5 percent) and the number of scientific publications went up by 52.1 percent, but there was a fall in resident patent applications by 20.3 percent in the same broad time period. It is this sharp divergence between the growth in the

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research effort and output, and decline in the number of patents which forms the empirical question addressed through the Innovation Index developed based on PCA in section 4.2 and further in section 5.

International migrants' stock, available only for every five years, exhibited an increase consistently at all points observed, from 13.7 percent of the population in 2005 to 19.8 percent in 2024 (Table 6).

Table 6. International Migrant Stock (% of Population), Germany (Reported Years Only)

Year	**2005**	**2010**	**2015**	**2020**	**2024**
Migrant stock (% of population)	13.7%	14.4%	15.4%	18.0%	19.8%

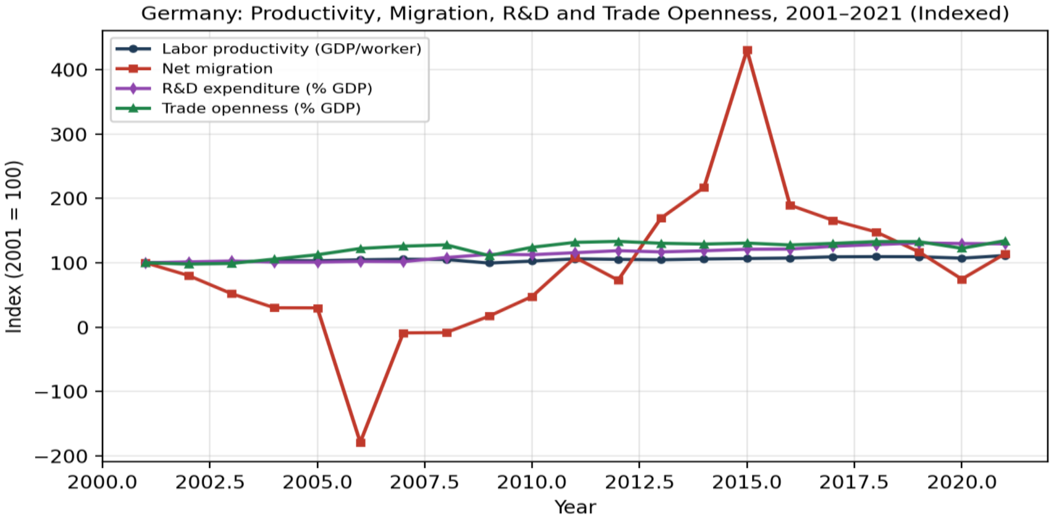

Figure 2. Indexed trends (2001 = 100) in labor productivity, net migration, R&D expenditure, and trade openness, Germany, 2001–2021. Source: authors' calculations from World Bank WDI data.

The PCA-Based Innovation Index

As was explained in Section 3.2, the Innovation Index is the first principal component of four standardized innovation measures that account for 84.5 percent of their common variance. This figure shows the calculated index from 2001 to 2021. As can be seen from the figure, the index grows almost monotonically from -2.79 in 2001 to +3.79 in 2021 due to the predominant growing impact of R&D, researchers' employment, and scientific publications compared with a decreasing patent series.

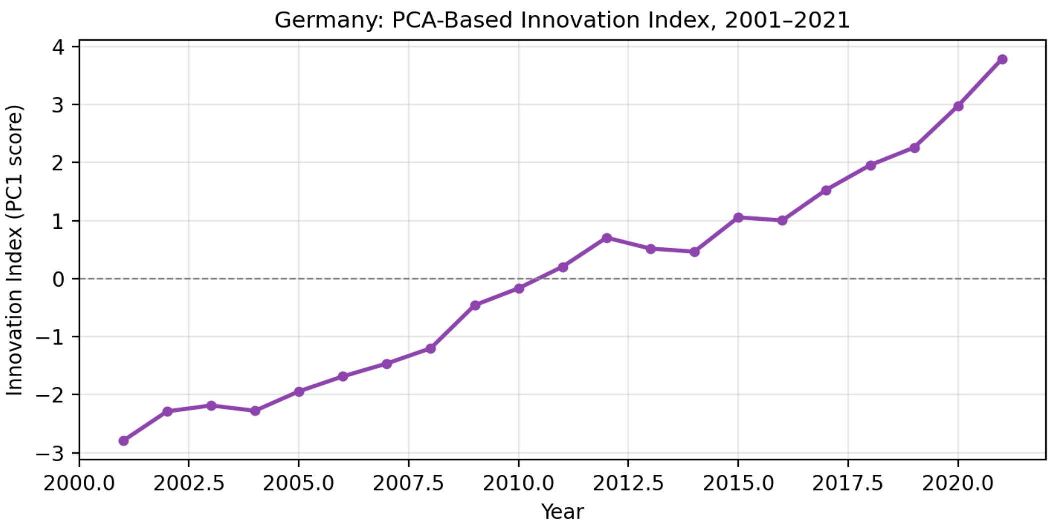

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Figure 3. PCA-based Innovation Index, Germany, 2001–2021 (PC1 scores). Source: authors' calculations from World Bank WDI data.

Correlation Analysis

Correlations among the main variables from 2001 to 2021 (n=21) are presented in Table 7. The Innovation Index has a very high correlation with labor productivity (r=0.836) and trade openness (r=0.761), as well as moderate correlation with net migration (r=0.453) and capital formation (r=0.388). Net migration has a moderate correlation with productivity (r=0.343). The share of the labor force with advanced education is negatively correlated with practically all other variables, including productivity (r=-0.579) and the Innovation Index (r=-0.742), considering the small and gradual change in this share and significant movement in the other variables over 20 years, this most likely represents a broad shift in the composition of the German labor force, such as increased labor force growth reducing the share of workers with advanced education despite an increase in their number and in Germany’s efforts in R&D; it is an interesting correlation to study in further research when using a decomposed index instead of a simple share.

Table 7. Correlation Matrix, 2001–2021 (n = 21)

	Productivity	**Migration**	**Adv. Educ. %**	**Innov. Index**	**Capital Form.**	**Trade %**	**FDI %**
Productivity	1.000	0.343	−0.579	0.836	0.484	0.829	0.222
Net migration	0.343	1.000	−0.230	0.453	0.081	0.317	−0.023
Adv. education %	−0.579	−0.230	1.000	−0.742	−0.103	−0.663	−0.136
Innovation Index	0.836	0.453	−0.742	1.000	0.388	0.761	0.388
Capital formation	0.484	0.081	−0.103	0.388	1.000	0.243	0.501
Trade %	0.829	0.317	−0.663	0.761	0.243	1.000	0.085
FDI %	0.222	−0.023	−0.136	0.388	0.501	0.085	1.000

Mediation Analysis

The a-path regression of the Innovation Index with net migration is presented in Table 8 below. Net migration is a statistically significant positive predictor of the Innovation Index (coefficient = 0.270 for each 100,000 net migrants, p = 0.039), and 20.5 percent of variation in the index can be explained by the model ($R^2 = 0.205$). This is the first instance in the current research project where the relationship between migration and the innovation indicator becomes statistically significant.

Table 8. Step 1 (Path a): Innovation Index ~ Net Migration (n = 21)

Predictor	**Coefficient**	**Std. Error**	**p-value**
Constant	−0.691	0.489	0.173
Net migration (per 100,000)	0.270	0.122	0.039**

$R^2 = 0.205$; Adjusted $R^2 = 0.163$; $F(1,19) = 4.90$, $p = 0.039$.

The total effect model (path c) for the relationship between productivity and net migration along with the three control variables, excluding the Innovation Index, is shown in Table 9. The total effect of migration on productivity is positive, but it is insignificant (coefficient = 104.49, p = 0.483). The strongest control variable is the trade openness ratio, which is highly significant ($p < 0.001$).

Table 9. Total Effect (Path c): Productivity ~ Net Migration + Controls, No Mediator (n = 21)

Predictor	**Coefficient**	**Std. Error**	**p-value**
Constant	73,260	8,295.3	0.000***
Net migration (per 100,000)	104.49	145.4	0.483
Gross capital formation	865.11	415.1	0.054*
Trade (% of GDP)	368.54	64.4	0.000***
FDI (% of GDP)	52.29	441.5	0.907

$R^2 = 0.779$; Adjusted $R^2 = 0.724$; $F(4,16) = 14.13$, $p < 0.001$.

The mediation model (b and c′ paths) along with the inclusion of the Innovation Index variable in the productivity regression equation is shown in Table 10. In the full model, the Innovation Index proves to be a statistically significant positive predictor of productivity (coefficient = 933.38; p = 0.036), regardless of the control for net migration, capital formation, trade, and FDI. After the inclusion of the Innovation Index, the net migration coefficient decreases in size and becomes negative (−36.15) from +104.49 in the total-effect model and is not statistically significant (p = 0.804).

Table 10. Full Model (Paths b, c′): Productivity ~ Migration + Innovation Index + Controls (n = 21)

Predictor	**Coefficient**	**Std. Error**	**p-value**
Constant	87,420	9,586.4	0.000***
Net migration (per 100,000)	−36.15	142.8	0.804
Innovation Index	933.38	404.9	0.036**
Gross capital formation	787.59	369.9	0.050*
Trade (% of GDP)	214.40	87.9	0.028**
FDI (% of GDP)	−428.78	443.9	0.349

$R^2 = 0.837$; Adjusted $R^2 = 0.783$; $F(5,15) = 15.41$, $p < 0.001$.

The pattern observed across Tables 8–10 is a significant a-path, a significant b-path, a non-significant total effect (c), and an attenuated, sign-reversing direct effect (c′) is consistent with what the mediation literature describes as indirect-only or inconsistent mediation, rather than the more common partial mediation pattern, where the total effect is significant and decreases toward, but does not reach, zero.

The formal Sobel test for the indirect effect ($a \cdot b = 0.270 \times 933.38 = 252.41$) produces a positive and suggestive result, but it is not statistically significant at the conventional 5 percent level, although it falls within the range often considered marginal or weak evidence at the 10 percent level.

Because the total effect (c = 104.49) is relatively small and not statistically significant, a direct "proportion mediated" calculation (indirect effect ÷ total effect) is not reported, as it would produce an unstable and difficult-

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to-interpret value in this case. Consistent with standard guidance in the mediation literature (e.g., MacKinnon, 2008), the Sobel z-statistic and the pattern of coefficients across Tables 8–10 are used as the primary evidence for interpreting the mediation relationship.

DISCUSSION

This study's central contribution is to show what a simple direct-effect regression would miss: once innovation is modeled explicitly as a mediating channel, Germany's aggregate time series speaks more clearly to how migration reaches productivity than a bivariate correlation ever could. The mediation results in Section 4.4 provide more substantive support for the innovation-mediation hypothesis than was possible with a shorter annual sample. Net migration has a significant effect on the Innovation Index (path a), and the Innovation Index also has a significant effect on labor productivity, even after controlling for migration and standard economic factors (path b). This significant two-stage pathway, together with the reduction and sign reversal of the direct migration effect after innovation is included (path c′), supports the theoretical argument discussed in Section 2: skilled immigration influences productivity substantially through its association with a country’s innovation intensity rather than only through a direct labor-supply channel. This finding is broadly consistent with Hunt and Gauthier-Loiselle (2010), who showed that immigrant college graduates contribute disproportionately to patenting activity, and with Peri (2012), who argued that immigration affects productivity not only through workforce size but also through changes in production techniques and skill intensity.

At the same time, the marginal Sobel test result ($p = 0.110$) means that this evidence should be interpreted as suggestive of mediation rather than definitive proof. The Sobel test is known in the methodological literature to be conservative in small-to-moderate samples, and the current analysis has a sample size of $n = 21$, which is below the level (typically above 30–50 observations) where mediation estimates are considered more stable. The most appropriate interpretation of these results is that they provide a stronger empirical signal than the purely descriptive correlations available from the earlier, shorter sample, while still not being sufficient for fully conclusive inferential mediation testing at the national level. Therefore, the findings should be understood as supporting evidence rather than final confirmation.

The negative PCA loading of resident patent applications, together with the positive loadings of R&D expenditure, researchers, and publications (Section 4.2), indicates a genuine divergence within Germany’s innovation system during 2001-2021. Higher R&D investment, researcher numbers, and publication output were accompanied by declining resident patent filings. Several overlapping explanations may account for this pattern. First, Germany’s research activities may have increasingly shifted toward publication-oriented, pre-commercial, or academic research rather than patentable, commercially oriented innovation, as discussed in broader European innovation policy debates. Second, changes in global patent-filing strategies may have influenced these trends, with German firms increasingly filing patents first or exclusively in other jurisdictions, such as through the European Patent Office or in expanding Asian markets (European Patent Office, 2024), rather than reflecting a true decline in inventive activity. Third, continued R&D investment in mature German manufacturing sectors may generate process innovations that are less likely to be patented. Distinguishing between these explanations is beyond the scope of a national aggregate time-series analysis and requires further research at the firm or sector level.

The negative correlation between the share of the labor force with advanced education and productivity outcomes, as well as the Innovation Index (Section 4.3) appears unexpected and should be interpreted cautiously. This relationship likely reflects changes in the composition of the denominator rather than a negative relationship between education, productivity, and innovation. While the share of the labor force with advanced education declined slightly, productivity and innovation increased substantially over the same period, partly due to changes in labor-force composition caused by factors such as EU labor mobility and demographic developments. Therefore, the negative correlation is more plausibly explained by changes in overall workforce characteristics rather than by a causal effect in which higher workforce education reduces productivity or innovation. This finding is reported transparently rather than excluded, consistent with the paper’s approach of explaining unexpected results instead of selectively reporting only supportive findings.

Read together, the a-path, b-path, and attenuated c′-path in Sections 4.4–5 tell a consistent story: migration's fingerprint on German productivity runs mainly through the innovation system, not through a large, separately identifiable labor-supply effect. From a policy perspective, the finding that migration affects productivity largely through innovation rather than through a large and statistically detectable direct effect is broadly consistent with the rationale behind Germany's 2020 and 2023 Skilled Immigration Act reforms. These reforms were designed to address skill shortages that policymakers viewed as limiting innovation capacity, particularly in STEM-related occupations. If the productivity benefits of skilled immigration operate mainly through innovation rather than direct labor supply, as suggested by the results, then the success of these reforms should be evaluated partly through their effects on Germany's research and innovation indicators rather than only through employment or productivity outcomes. However, the current estimation sample (2001–2021) cannot yet assess the impact of these reforms because the major amendments were introduced only in November 2023. Further years of post-reform data will be required for future evaluation.

Limitations

Beyond the limitations discussed in Section 3.4, this study has several additional constraints. First, the analysis is conducted at the national level, treating Germany as a single unit. Therefore, it does not capture regional (Bundesländer) heterogeneity, which may be substantial due to differences in industrial structure, immigrant settlement patterns, and innovation infrastructure across German states, as demonstrated by Niebuhr (2010) using sub-national data.

Second, although the mediation model's sample size (n = 21) represents a considerable improvement compared with the 6–9 observations available in the initial exploratory version of this analysis, it remains relatively small for stable mediation-model inference. Therefore, the marginal significance of the Sobel test ($p = 0.110$) should be interpreted cautiously and not as definitive confirmation of mediation. Bootstrap resampling methods are generally recommended over the Sobel test precisely for this reason (Preacher & Hayes, 2008; Zhao, Lynch, & Chen, 2010), and applying them to an extended, post-2023-reform sample is identified as a priority for future work in Section 7.

Third, net migration is an imperfect measure of high-skilled immigration because it includes all cross-border population movements regardless of visa category, skill level, or migration purpose. It includes various forms of migration, such as family reunification, humanitarian migration, and intra-EU mobility. A more accurate examination of the research question would require immigration data disaggregated by education level or visa category, particularly information on EU Blue Card issuances, such as data available from Destatis or the Bundesagentur für Arbeit.

Fourth, although the Innovation Index is statistically supported by a single-component solution (84.5% of variance explained), it combines measures of innovation inputs (R&D expenditure and researcher numbers) with an innovation output measure (resident patent applications) that has an opposite loading direction. Therefore, the index should not be interpreted as a simple "more innovation is always better" scale in every context.

Fifth, several control and mediator variables are correlated with each other and with time (Section 3.4), creating a degree of multicollinearity that is common in long-term single-country time-series analysis. This increases the uncertainty around individual coefficient estimates, even when the overall model fit remains strong.

Finally, patent, R&D, researcher, and publication data are unavailable for most series after 2021, meaning that this analysis cannot yet capture the potential effects of Germany's 2023 Skilled Immigration Act reform, which represents the most policy-relevant recent development in this area.

CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

This paper examined whether high-skilled immigration affects labor productivity in Germany and whether this relationship is mediated by innovation. Using a mediation approach based on Baron and Kenny's framework and a PCA-based Innovation Index, the study investigated whether innovation serves as a formal mediating channel between migration and productivity. The results support the central hypothesis of the paper, although not conclusively: net migration significantly predicts the Innovation Index, the Innovation Index significantly predicts labor productivity after controlling for migration and other standard economic factors; and the direct effect of migration on productivity decreases in magnitude and loses statistical significance once innovation is taken into account. However, the formal Sobel test of the indirect effect is not statistically significant ($p = 0.110$), meaning that the mediation effect should be interpreted as suggestive rather than definitive.

The findings are consistent with the broader international literature on the relationship between skilled immigration, innovation, and productivity gains, as demonstrated by Hunt and Gauthier-Loiselle (2010), Peri (2012), and Kerr and Lincoln (2010). They also highlight an important research challenge that requires further investigation: the simultaneous increase in R&D effort and publication output alongside a decline in resident patent filings. Understanding this divergence requires analysis beyond a national aggregate time series.

From a policy perspective, the results suggest that the main channel through which migration is associated with productivity is innovation rather than a large direct labor-supply effect. This finding is broadly consistent with the objectives of Germany's Skilled Immigration Act reforms in 2020 and 2023, which focused on addressing shortages in STEM and other innovation-relevant occupations. However, due to the significant data limitations identified throughout this study, these findings should be viewed as motivation for further targeted research rather than as a standalone basis for strong policy conclusions.

Several directions for future research follow from the limitations of this study. First, future research should use state-level (Bundesländer) panel data, such as data from Destatis's Regionaldatenbank Deutschland, the Institute for Employment Research (IAB), or Eurostat regional statistics, to estimate the same mediation model with both cross-sectional and time-series variation, extending the approach used by Niebuhr (2010). Second, future studies should apply more skill-specific immigration measures, such as EU Blue Card issuance data, rather than total net migration, to examine whether high-skilled immigration has stronger effects through innovation-related channels. Third, as more post-reform data become available, researchers should revisit this model to evaluate the specific effects of the 2023 amendments to the Skilled Immigration Act. Future studies should also investigate, using firm-level or patent-office-level data, the divergence between increasing R&D inputs and outputs and declining resident patent filings identified in Section 4.2, as this issue has important implications for how innovation should be measured in future research. Taken together, these results shift the relevant policy question from whether skilled immigration raises German output on average to how it does so chiefly by feeding the innovation system rather than simply enlarging the workforce a distinction that matters directly for how the 2020 and 2023 Skilled Immigration Act reforms should ultimately be evaluated.

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APPENDIX

Table A1. Descriptive Summary Statistics of WDI Variables (2001–2025)

Variable	**N**	**Mean**	**Std. Dev.**	**Min**	**Max**
GDP per worker (const. 2021 PPP $)	25	119,066.1	4,196.2	111,750.7	125,725.5
Net migration (persons)	25	266,474.1	355,691.2	−489,056	1,175,283
International migrant stock (% pop.)	5	16.26	2.56	13.70	19.80
Labor force, advanced education (%)	24	74.05	0.88	72.69	75.94
Patent applications, residents	21	47,158.3	2,233.1	39,822	49,989
R&D expenditure (% of GDP)	23	2.75	0.27	2.38	3.15
Researchers in R&D (per million)	23	4,356.6	899.2	3,230.3	5,926.1
Scientific/technical journal articles	23	97,189.5	14,495.0	71,323.3	117,127.5
Gross capital formation (% of GDP)	25	20.64	1.35	18.01	23.28
Trade (% of GDP)	25	74.13	7.74	58.33	88.79
FDI, net inflows (% of GDP)	25	2.07	1.06	−0.72	4.49

N varies by series due to differing WDI reporting windows (see Table 2). Summary statistics computed over the full 2001–2025 sample as available per series.

Table A2. Principal Component Analysis (PCA) Loadings and Score Variance

Innovation Indicator	**PC1**	**PC2**	**PC3**	**PC4**
R&D expenditure (% of GDP)	0.531	0.223	0.461	−0.675
Researchers in R&D (per million)	0.536	0.159	0.383	0.735
Scientific/technical journal articles	0.516	0.319	−0.794	−0.031
Patent applications, residents	−0.406	0.907	0.099	0.048

Eigenvalues and share of variance explained: PC1 = 3.381 (84.5%); PC2 = 0.537 (13.4%); PC3 = 0.072 (1.8%); PC4 = 0.010 (0.3%). Component normalization: sum of squares of each column = 1. PC1 is used as the Innovation Index throughout the paper (Section 3.2).

Table A3. Pearson Correlation Matrix of Model Variables (2001–2021)

	Productivity	**Migration**	**Adv. Educ. %**	**Innov. Index**	**Capital Form.**	**Trade %**
Migration	0.343 (0.128)					

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Adv. Educ. %	-0.579 (0.006)	-0.230 (0.316)				
Innov. Index	0.836 (<0.001)	0.453 (0.039)	-0.742 (<0.001)			
Capital Form.	0.484 (0.026)	0.081 (0.727)	-0.103 (0.657)	0.388 (0.082)		
Trade %	0.829 (<0.001)	0.317 (0.161)	-0.663 (0.001)	0.761 (<0.001)	0.243 (0.289)	
FDI %	0.222 (0.334)	-0.023 (0.921)	-0.136 (0.557)	0.388 (0.082)	0.501 (0.021)	0.085 (0.714)

Cell entries are Pearson r with the two-tailed p-value in parentheses (n = 21, 2001–2021). Upper triangle omitted (matrix is symmetric); see Table 7 for the r-only matrix.

Table A4. Baron and Kenny Three-Equation Mediation Regression Results

Predictor	**(1) Path a: Innovation Index**	**(2) Path c: Total Effect**	**(3) Paths b, c′: Full Model**
Net migration (per 100,000)	0.270** (0.122)	104.49 (145.4)	−36.15 (142.8)
Innovation Index			933.38** (404.9)
Gross capital formation		865.11* (415.1)	787.59* (369.9)
Trade (% of GDP)		368.54*** (64.4)	214.40** (87.9)
FDI (% of GDP)		52.29 (441.5)	−428.78 (443.9)
Constant	−0.691 (0.489)	73,260*** (8,295.3)	87,420*** (9,586.4)
Observations	21	21	21
R^2	0.205	0.779	0.837
Adjusted R^2	0.163	0.724	0.783
F-statistic	4.90 (1,19)	14.13*** (4,16)	15.41*** (5,15)

*Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Column (1) reproduces Table 8; column (2) reproduces Table 9; column (3) reproduces Table 10, consolidated here for side-by-side comparison as in the classic Baron and Kenny (1986) three-equation layout.*

Table A5. Sobel Test of the Indirect (Mediated) Effect

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Quantity	Value
Path a coefficient (net migration → Innovation Index)	0.270
Path a standard error	0.122
Path b coefficient (Innovation Index → Productivity)	933.38
Path b standard error	404.9
Indirect effect (a × b)	252.41
Standard error of indirect effect (delta method)	157.85
Sobel z-statistic	1.60
Two-tailed p-value	0.110
Approx. 95% CI for indirect effect	−56.98 to 561.80

Sobel (1982) test: $z = (a \cdot b) / \sqrt{(b^2 SE_a^2 + a^2 SE_b^2)}$*, using the path-a coefficient from Table 8 and the path-b coefficient from Table 10.*