Universidade de São Paulo
Faculdade de Economia, Administração e Contabilidade de Ribeirão Preto
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Programa de Pós-Graduação em Economia — Área: Economia Aplicada

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Essays on economic growth

Ensaios sobre crescimento econômico

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Ribeirão Preto
2023

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Tese apresentada ao Programa de Pós-Graduação em Economia — Área: Economia Aplicada da Faculdade de Economia, Administração e Contabilidade de Ribeirão Preto da Universidade de São Paulo, para obtenção do título de Doutor em Ciências. Versão Corrigida. A original encontra-se disponível na FEA-RP/USP.

Supervisor: Prof. Dr. Luciano Nakabashi

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Ribeirão Preto

2023

Ribeiro, Marcos Júnio
Essays on economic growth / Universidade de São Paulo – USP
Faculdade de Economia, Administração e Contabilidade de Ribeirão Preto
Departamento de Economia
Programa de Pós-Graduação em Economia - Área: Economia Aplicada;
Supervisor: Prof. Dr. Luciano Nakabashi
Ribeirão Preto, 2023- 140 p. : il. 30cm

Tese de Doutorado – Universidade de São Paulo, 2023.

1. Crescimento Econômico. 2. Capital Humano. 3. Investimento Estrangeiro Direto. 4. Má alocação de Recursos. 5. Produtividade. 6. Mudança Estrutural. I. Orientador: Prof. Dr. Luciano Nakabashi. II. Co-orientador: Prof. Dr. Fernando A. Barros Jr. III. Universidade de São Paulo. IV. Faculdade de Economia, Administração e Contabilidade de Ribeirão Preto.

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Title: Essays on economic growth

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Approved in: 25/01/2024

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Acknowledgements

I would like to thank my advisor, **Luciano Nakabashi**, for his support in my thesis work, for his valuable macroeconomics lessons and for his guidance during all the research we did together. Our partnership over the five years of my doctorate was very successful and gave me a lot of learning. I also want to express my gratitude to my co-supervisor, **Fernando Barros Jr**, for his support and commitment to the papers we produced together. Our weekly meetings have always been very productive and have added a lot of knowledge to me. I am also very grateful to **Fernando Barros Jr** for having the patience to teach me how to work with computable general equilibrium models. I extend my thanks to Professor **Bruno Delalibera** for his support, particularly in the third paper of this thesis, and for sharing insights about professional and academic life. The dedication, hard work, patience, and professional journey of these three economists will always be a source of inspiration for me.

I would like to thank the members of the committee, **Maurício Bittencourt**, **Luiz Brotherhood**, **Tomás Martinez**, and **Pedro Cavalcanti**, for their valuable contributions to our research. I am grateful to Professors **Fábio Gomes** and **Luiz Brotherhood** for their conversations and insights during the initial phase of my thesis project. I also appreciate the teachings of Professor **Jefferson Bertolai**, who instilled in us the importance of rigor in our work. I would also like to express my gratitude to the professors at FEARP, **Márcio Poletti Laurini**, **Sérgio Kannebley Júnior**, **Fábio Barbieri** and **Sergio Naruhiko Sakurai**, for the knowledge imparted during my doctoral studies, which has been incredibly valuable. Finally, I would also like to thank the staff at the department, particularly **Selma Lúcia Rocha Pontes** and **Érika de Lima Veronezi Costa** for their support.

The present work was carried out with the support of the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) - Financing Code 001.

Abstract

RIBEIRO, M. J. (2023) **Essays on Economic Growth**. Doctoral Dissertation - Faculdade de Economia, Administração e Contabilidade de Ribeirão Preto, Universidade de São Paulo, Ribeirão Preto, 2023.

This doctoral dissertation comprises three independent papers focusing on economic growth. The first paper investigates the impact of foreign direct investment (FDI), specifically through greenfield and mergers and acquisitions, on Brazilian economic growth. Findings reveal that while FDI alone does not significantly influence Brazilian growth, its positive effects are enhanced by local conditions. Notably, FDI via greenfield positively impacts Brazilian growth, while the effects of FDI through mergers and acquisitions and FDI volatility are negligible. The second paper explores the misallocation of talent in the Brazilian labor market, particularly among teachers, and its adverse effects on the workforce and economic development. Barriers in the labor and education markets lead to talent misallocation, hindering economic growth. Eliminating these barriers could result in a substantial 16.94% increase in Brazilian income. The third paper examines the spillover effects of intermediate goods on income per worker, using a general equilibrium model with four sectors: agriculture, industry, traditional services, and modern services sectors. The study demonstrates that closing the productivity gap in the industry has a more significant average impact on GDP per worker and aggregate productivity compared to other sectors. Furthermore, in countries with highly efficient agricultural and industrial sectors, a structural change favoring the services sector, without a necessary increase in productivity, exacerbates the gap in GDP per worker between countries.

Keywords: Economic growth; Direct Foreign Investment; Misallocation of Talent; Human capital; Productivity; Intermediate Goods.

Resumo

RIBEIRO, M. J. (2023) **Ensaios sobre Crescimento Econômico**. Tese (Doutorado) - Faculdade de Economia, Administração e Contabilidade de Ribeirão Preto, Universidade de São Paulo, Ribeirão Preto, 2023.

Esta tese de doutorado é composta por três artigos independentes centrados no crescimento econômico. O primeiro artigo investiga o impacto do investimento estrangeiro direto (IED), especificamente por meio de greenfields e fusões e aquisições, no crescimento econômico brasileiro. Os resultados revelam que, embora o IDE por si só não influencie significativamente o crescimento brasileiro, seus efeitos positivos são potencializados pelas condições locais. Notavelmente, o IDE via greenfield impacta positivamente o crescimento brasileiro, enquanto os efeitos do IDE através de fusões e aquisições e a volatilidade do IDE são insignificantes. O segundo artigo explora a má alocação de talentos no mercado de trabalho brasileiro, especialmente entre os professores, e seus efeitos adversos sobre a força de trabalho e o desenvolvimento econômico. As barreiras nos mercados de trabalho e de educação conduzem a uma má alocação de talentos, dificultando o crescimento económico. Remover essas barreiras poderia resultar em um aumento substancial de 16,94% na renda brasileira. O terceiro artigo examina os efeitos de transbordamento dos bens e serviços intermediários no rendimento por trabalhador, utilizando um modelo de equilíbrio geral com quatro setores: agricultura, indústria, serviços tradicionais e serviços modernos. O estudo demonstra que fechar o gap de produtividade na indústria tem um impacto médio mais significativo no PIB por trabalhador e na produtividade agregada em comparação com os outros setores. Além disso, mostramos que em países cujos setores agrícolas e industriais são altamente eficientes, uma mudança estrutural que favoreça o setor dos serviços, sem o devido aumento de produtividade, aumenta ainda mais o gap no PIB por trabalhador entre países.

Palavras-chaves: Crescimento Econômico; Investimento Estrangeiro Direto; Má Alocação de Talentos; Capital Humano; Produtividade; Bens Intermediários.

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1 General Introduction

This doctoral dissertation consists of three self-contained papers on economic growth. In the first paper, we analyze the effects of foreign direct investment via greenfield and mergers and acquisitions on Brazilian economic growth. In the second paper, we analyze how the misallocation of talent in the Brazilian labor market, especially teachers, harms the workforce and economic development. Both papers were published in different journals. In the third paper we evaluate the role of intermediate goods and services in the economic development.

In the first paper we evaluate the effects of foreign direct investment (FDI) on Brazilian economic growth between 1996 and 2018, considering three aspects: local conditions in Brazil, the two types of FDI, greenfield and mergers and acquisitions (M&As), and their volatility. Therefore, we build a model that considers the effects that volatility and the two different types of FDI can have on growth. To test the model's main hypotheses, we estimated the econometric model SVAR and concluded that FDI alone does not influence Brazilian growth. However, local conditions enhance its positive effects. In addition, we show that FDI via greenfield has a positive impact on Brazilian growth. On the other hand, the effect of FDI by M&As and FDI volatility are null. This paper was published in Revista Brasileira de Economia Vol. 76, No. 2 (Apr–Jun 2022) 197–223.

In the second paper we investigate the allocation of talent in the labor market in an economy where teachers are the cornerstone in the development of the human capital of the workforce. For this, we elaborate a general equilibrium model with barriers in the labor market and in the educational goods market, these barriers affect the allocation of talents in the economy. Our analysis suggests that when individuals with greater abilities choose a teaching career, the entire workforce benefits. However, barriers in labor and education markets can lead to misallocation of talent and hinder economic growth and development. Our model is calibrated for the Brazilian economy, and our findings reveal a negative correlation between barriers in teacher occupation and per capita output across

Brazilian states. Our results also indicate that the elimination of all barriers in the labor market can result in a 16.94% increase in Brazilian income. This paper was published in the Journal of Macroeconomics Vol. 77, September 2023.

In the third and final paper of this thesis we study the spillover effects of intermediate goods on income per worker. Therefore, we developed a general equilibrium model, with four sectors (agriculture, industry, traditional services and modern services), to quantitatively evaluate the effects of changes in productivity and productive structure on the income gap, in developed and developing countries. We then show that closing the productivity gap in industry has a greater average impact on GDP per worker and aggregate productivity, when compared to other sectors. Furthermore, we show that in countries with highly efficient agricultural and/or industrial sectors, a structural change that increases the share of the services sector in the economy, without the necessary increase in productivity, would further increase the disparity in GDP per worker.

2 Foreign Direct Investment: Greenfield, by Mergers and Acquisitions, Volatility and Their Effects on Brazilian Economic Growth

Abstract

In this article, we assess the effects of foreign direct investment (FDI) on Brazilian economic growth between 1996 and 2018, considering three aspects: Brazil's local conditions, the two types of FDI, which are through *greenfield* and through mergers and acquisitions (M&As), and its volatility. To accomplish this objective, we employ the SVAR econometric model. The results show that FDI alone does not influence Brazilian growth. However, local conditions amplify its positive effects. It was also observed that *greenfield* FDI has a positive impact on Brazilian growth. On the other hand, the effect of FDI through M&As and the volatility of FDI are negligible.

Keywords: foreign direct investment, economic growth, volatility

2.1 Introduction

Brazil has had a prominent position in terms of foreign direct investment (FDI) inflows. In 2018, it was the sixth largest recipient of FDI globally, with 61 billion dollars, behind only the United States, China, Hong Kong, Singapore, the Netherlands, and the United Kingdom (UNCTAD, 2019). This form of investment is established in the host country through mergers and acquisitions (M&As) or by means of greenfield investments ($FDI_{M\&As}$ and FDI_{GRF} respectively), thus becoming a significant source of financing for developing nations.[1] Compared to short-term capital inflows like portfolio investments and credit, FDI is the most important form of external financing due to its stability even in the face of negative changes in the economic environment of the host country (OZTURK, 2012).

Consequently, FDI has been highly sought after by countries, as it can yield benefits to the host economy. Among these benefits are trade surpluses, higher employment levels, improved technological capacity, economic modernization, and economic growth (CRESPO; FONTOURA, 2007; BITTENCOURT, 2016; CASTRO; CAMPOS, 2018). The theory regarding the effects of FDI on growth emphasizes that multinational enterprises (MNEs), upon establishing themselves in the host country, generate technology and knowledge spillovers for domestic firms, potentially leading to economic growth. The channels through which these spillovers occur include imitation/demonstration, labor mobility, exports, competition, and relationships between customers and suppliers (CRESPO; FONTOURA, 2007).

However, a significant portion of empirical studies, including those involving Brazil, have found that FDI only increases productivity in countries possessing a specific set of characteristics.[2] The key factors indicated in the literature include the level of human capital, a developed financial market, institutional quality, macroeconomic stability, and trade openness, among others (BORENSZTEIN; GREGORIO; LEE, 1998; ALFARO et

[1] Greenfield investment refers to when a company builds new facilities, through projects, outside its country of origin (BURGER; KARREMAN; EENENNAAM, 2015).

[2] The study by Bittencourt (2016), focusing solely on the Brazilian case, which demonstrated that when these characteristics are not taken into account, FDI can hinder Brazilian economic growth.

al., 2004; ELBOIASHI, 2015; BITTENCOURT, 2016; HAYAT, 2019).

Another relevant point is that FDI_{GRF} has a greater capacity to expand the capital of host countries, deepen their technological structure and generate growth. Bittencourt (2016) emphasizes that in Brazil, FDI_{GRF} contributed to increased production and reduced importation of manufactured products, improved wages and higher levels of employment, as well as economic growth through technology and knowledge spillovers. Conversely, $FDI_{M\&As}$ generates income for the owner of the acquired company, and such income might not be reinvested. In this case, it does not convert (HARMS; MÉON, 2018).

It should be noted that financial crises can have negative impacts on the determinants of FDI, and on its flow (CASTRO; CAMPOS, 2018).[3] Due to the economic crisis of 2008, there was a significant decrease in FDI flows to Brazil, as highlighted by Filho (2015). Therefore, the volatility of FDI (FDI_{vol}) can be understood as a proxy for the host country's macroeconomic instability, potentially leading to adverse effects on growth.

However, many studies that measured the effects of FDI on Brazilian growth ignored these essential facts. Given this context, this article aims to investigate how FDI, its two modalities (FDI_{GRF} and $FDI_{M\&As}$), its volatility, as well as Brazilian macroeconomic and institutional characteristics, were related to economic growth between 1996 and 2018.

It is worth noting that, due to the scarcity of studies on the relationship between FDI_{GRF}, $FDI_{M\&As}$, FDI_{vol}, and Brazilian economic growth, this relationship is not yet clear. The central questions that arise regarding the impact of FDI on Brazilian growth are (i) Are they positive, negative, or neutral? (ii) Which modality has the greatest impact, FDI_{GRF} or $FDI_{M\&A}$? (iii) Do high levels of human capital, a large financial market, trade openness, and institutional quality amplify potential positive effects? (iv) Does their respective volatility have an adverse effect? Answering these questions can help clarify the role of FDI inflows in Brazilian economic growth and provide important information to economic policy makers and other stakeholders.

[3] Some determinants of FDI found in the literature include country risk, market and political risk, exchange rate volatility, return on investment, among others (MOOSA, 2015).

This article differentiates itself from previous research due to the following factors: a) it uses a database covering a less explored period in the literature, 1996-2018, during which there was a significant increase in FDI flows to Brazil; b) it considers two types of FDI (FDI_{GRF} and $FDI_{M\&As}$) since both can have distinct effects on growth; c) FDI volatility is also taken into account, as it is related to the uncertainty of the Brazilian economic scenario and the global economy, and also due to its potential to cause adverse effects on growth.

To achieve the proposed objectives, in addition to this introduction, Section 2.2 provides a review of the literature that includes several studies that investigate the relationship between FDI and growth in Brazil and other countries. In Section 2.3, we develop a theoretical model based on Borensztein, Gregorio and Lee (1998), which also examines this relationship. The empirical strategy employed in the study, in this case the structural VAR, is discussed in Section 2.4. The results are presented in Section 2.5 and indicate that isolated FDI does not significantly affect growth, FDI_{GRF} has a greater impact than $FDI_{M\&As}$, and volatility has neutral effects. Finally, in Section 2.6, the main conclusions are presented.

2.2 FDI and Economic Growth: Empirical Evidence

Several researchers have examined the relationship between foreign direct investment (FDI), some of the locational factors of the host country, and economic growth. However, studies that relate FDI via greenfield, mergers and acquisitions, and FDI volatility (FDI_{GRF}, $FDI_{M\&As}$, and FDI_{vol} respectively) to economic growth are scarce. Some of these studies point to FDI as a driver of economic growth when the host country's institutional and macroeconomic characteristics are taken into account. Nevertheless, the results diverge, partly due to the wide variety of econometric techniques, specific sets of countries or economies, and different time periods used in the analyses (IAMSIRAROJ; ULUBAŞOĞLU, 2015).

In their seminal study, Borensztein, Gregorio and Lee (1998) analyzed the effects of FDI on the growth of a set of countries. The authors' main conclusion was that such effects are driven by the host country's level of human capital. Meanwhile, Alfaro et al. (2004) examined the relationship between FDI, financial development, and economic growth. The authors highlighted that the host country's financial development enhances the positive effects of FDI on growth, as this development reduces risks and allows efficient allocation of FDI resources.

Hayat (2019) provided evidence that institutional quality also amplifies the positive effects of FDI on growth. Better institutional quality increases competition between foreign and domestic companies, contributing to greater efficiency and innovation in the economic sectors. Furthermore, better institutional quality contributes to technology and knowledge spillovers and capital accumulation. The author suggested that countries intending to enhance their growth through FDI should combat corruption and strengthen the rule of law.[4]

In particular, the research by Carkovic and Levine (2005) and Damasceno (2013) did not find a relationship between FDI and growth. The former justifies that the results attributing growth to FDI might stem from model misspecification in the employed econometric model. The latter highlights that FDI flows might lead countries into financial crises, macroeconomic instability, and currency appreciation, negatively affecting growth.

Other researchers analyzed the effects of FDI solely on Brazilian economic growth. For example, Fernandes (2006) emphasized that FDI did not influence Brazilian economic growth between 1970 and 2003. The rationale behind this lies in the fact that FDI in Brazil occurred through M&As or was predominantly directed to the services sector. Similarly, Mortatti (2011) did not find a significant relationship between FDI and Brazilian growth. On the other hand, Carminati and Fernandes (2013) found that FDI has a positive influence on Brazilian growth, though its magnitude is small. The justification for this is similar to that of Fernandes (2006). Furthermore, Fraga, Parré and Silva (2013) found that FDI influenced the economic growth of 26 Brazilian states and the Federal District

[4] The rule of law captures perceptions of the extent to which agents trust and comply with the rules of society, particularly property rights, the quality of contract enforcement, the courts, and police, as well as the likelihood of crime and violence (KAUFMANN; KRAAY; MASTRUZZI, 2011).

in the years 1995, 2000, and 2005.

However, none of these studies that solely analyzed the Brazilian case took into account the country's macroeconomic and institutional factors that could aid in absorbing and converting FDI into growth. The importance of such factors becomes evident in the work of Bittencourt (2016), who found that when considered alone, FDI negatively influenced Brazilian economic growth. However, when they introduced the interaction variable $FDI*X$, where X could be human capital, infrastructure, or institutional quality, the effects on growth were positive.

Studies that examined the effects of FDI_{GRF} and $FDI_{M\&As}$ on growth are scarce. One such study is by Wang and Wong (2009), who analyzed a sample of 84 countries from 1987 to 2001. The findings were that FDI_{GRF} increases economic growth. In contrast, $FDI_{M\&As}$ only promotes growth in countries with high human capital. Furthermore, Harms and Méon (2018) examined a set of 127 developed and developing countries between 1990 and 2010. Their results indicate that FDI_{GRF} has a more significant positive effect on growth than $FDI_{M\&As}$.

Another relevant factor that seems to be associated with the potential effects of FDI on growth is its volatility. Lensink and Morrissey (2006) draw attention to the fact that the volatility of FDI flows can generate uncertainties in research and development (R&D) investment costs, discouraging multinational enterprises (MNEs) from innovating. Furthermore, the volatility of FDI flows, according to the authors, can serve as a proxy for the host country's political and economic uncertainties. A similar conclusion is reached by Castro and Campos (2018), who claim that international financial crises negatively impact FDI stocks.

2.3 Theoretical Model

According to Crespo and Fontoura (2007), foreign direct investment (FDI) can generate positive externalities, namely, technology and human capital spillovers, for the host country, leading to increased productivity. However, the country's ability to convert such spillovers into productivity growth can be conditioned by local factors. Thus, Borensztein, Gregorio and Lee (1998), based on Barro and Martin (1995), developed a theoretical model to explain the relationship between FDI, human capital, institutional and macroeconomic factors, and economic growth.

However, the model overlooks the fact that greenfield FDI and FDI through mergers and acquisitions (FDI_{GRF} and $FDI_{M\&As}$ respectively) have distinct effects on growth, as well as the possibility that volatility in FDI flows (FDI_{vol}) may increase uncertainty and production costs for multinational enterprises (MNEs) and, consequently, reduce growth. Thus, based on the model by Borensztein, Gregorio and Lee (1998), we have developed a model that considers the effects that volatility and the two different types of FDI can have on growth.

Hence, the model highlights the role of both FDI modalities and their volatility as determinants of economic growth and demonstrates their complementarity with human capital and other local factors of the host country. Furthermore, this model serves as the foundation for the empirical investigation discussed in Section 2.2.

Consider that the economy of a certain country produces a single good, so we have the following production function:

$$Y_t = A_t K_t^{(1-\alpha)} H_t^{\alpha}, \quad 0 < \alpha < 1, \tag{2.1}$$

where A represents local and institutional factors that influence productivity, H_t is human capital[5], and K_t represents the aggregation of different types of capital goods.[6] Productivity growth arises due to an increase in the number of varieties of these capital goods. The capital stock at each time instant is given by:

$$K_t = \left[\int_0^N d(q)^{1-\alpha} dq \right]^{\frac{1}{1-\alpha}}, \tag{2.2}$$

[5] Assumed to be given.

[6] According Borensztein, Gregorio and Lee (1998), A represents the exogenous state of the "environment." In this article, A includes trade openness, financial market size, institutional quality, and other measures that can enhance the effects of FDI on Brazilian growth.

where $d(q)$ represents the demand for each variety of capital good q, and N is the total number of varieties of these goods.[7] In this economy, there are two firms producing capital goods: domestic firms and foreign firms. Foreign production is carried out by multinational enterprises (MNEs) through FDI, where $M \in [M\&As, GRF]$. Domestic firms produce n units and foreign firms produce n^* units. Hence, the total capital goods produced is $N = n + n^*$. Firms producing capital goods are remunerated by renting them to firms producing final goods at a rate of $m(q)$. The demand for these capital goods occurs where $m(q)$ equals the marginal product of the q-th capital good. Thus, we have the following:

$$m(q) = A(1-\alpha)H^{\alpha}d(q)^{-\alpha}. \tag{2.3}$$

In this economy, MNEs are responsible for generating technology and knowledge spillovers to domestic firms, consequently driving the technological progress that occurs by facilitating the production of new capital goods. The channels through which such spillovers occur are imitation, whereby domestic firms copy technology through contact with foreign firms (ex-employees or observation), and competition, as the entry of foreign firms pressures domestic firms to enhance their technological structure and improve the quality of their products and services.[8]

However, the increase in capital goods production depends on the adaptation of technology from developed countries. We assume that technological adaptation incurs a cost F, inversely related to n^*/N.[9] Another significant point is that if FDI flows are uncertain (highly volatile), the costs of adapting to new technology are uncertain as well, which, in turn, could affect incentives for innovation and subsequently economic

[7] According to Barro and Martin (1995), it is more convenient to think of N as continuous rather than discrete, as when N is sufficiently large, the error becomes small. Barro and Martin (1995) also note that N can be used as a proxy for technological development, though we will not be using this assumption in our model.

[8] Due to the positive externalities arising from FDI that MNEs do not consider, foreign investments fall below what would be socially optimal. A central planner would take these effects into account to stimulate such investments. However, this aspect won't be explored in this article, as our focus is on the empirical relationships between FDI, economic performance, and the local conditions of the domestic economy.

[9] This assumption follows from the fact that foreign firms are the primary source of technological progress for domestic firms. Therefore, greater foreign presence implies more technology and knowledge spillovers for domestic firms, leading to a decrease in F.

growth (LENSINK; MORRISSEY, 2006). Consequently, higher FDI_{vol} increases the cost of technological adaptation.[10]

We also assume the existence of technological catch-up, as it is cheaper to imitate existing products in the market than to innovate. This can be represented by considering that the fixed cost F depends on the number of varieties of capital goods produced in the domestic economy, N, divided by the number of capital goods produced in the foreign economy, N*. In countries where the ratio N/N* is lower, there is a higher possibility of imitation and lower costs of adopting new technologies. Thus, the cost function can be represented as follows:

$$F = F(n^*/N, IDE_{vol}, N/N^*), \text{ where } \frac{\partial F}{\partial IDE} < 0, \ \frac{\partial F}{\partial IDE_{vol}} > 0 \text{ and } \frac{\partial F}{\partial N/N^*} > 0. \tag{2.4}$$

In addition to the fixed installation cost F, the firm incurs a marginal production cost of $d(q)$ equal to one, and the capital depreciates entirely every unit of time t. It is also assumed that, in the steady state, the interest rate r is constant. Therefore, the producer's profit from a new variety of capital q is given by:

$$L(q)_t = -F(n_t^*/N_t, IDE_{vol}, N_t/N_t^*) + \int_t^{\infty} [m(q)d(q) - 1d(q)]\, e^{-r(s-t)} ds, \tag{2.5}$$

where s is a future date, and $e^{-r(s-t)}$ is the discount factor. By maximizing Equation (2.5) subject to Equation (2.3), we find the equilibrium level for the production of each capital good $d(q)$:

$$d(q) = HA^{1/\alpha}(1-\alpha)^{2/\alpha}, \tag{2.6}$$

where $d(q)$ is constant at each time interval t. Furthermore, the production level of different varieties is also the same due to the symmetry in the way each capital good enters the production function. Substituting Equation (2.6) into Equation (2.3) yields the following expression for the rental rate:

$$m(q) = 1/(1-\alpha). \tag{2.7}$$

[10] We won't develop a structural model that directly relates FDI and its volatility to the costs of technological adaptation. We merely suggest a relationship based on partial derivatives. While this is an important derivation to pursue in a theoretical model, it would extend beyond the scope of this study.

This equation shows the rental rate of a variety of capital q as the profit margin over the maintenance costs of this good. Assuming free entry into the capital goods market, the rate of return r will be such that profits are equal to zero. Therefore, we have:

$$r = A^{1/\alpha}\phi F(n^*/N, IDE_{vol}, N/N^*)^{-1}H, \text{ where } \quad \phi = \alpha(1-\alpha)^{(2-\alpha)/\alpha}. \tag{2.8}$$

To conclude, it is necessary to describe the capital accumulation process provided by savings. It is assumed that individuals maximize the following standard intertemporal utility function:

$$U_t = \int_t^\infty \frac{c_s^{1-\sigma}}{1-\sigma} e^{-\rho(s-t)} ds, \tag{2.9}$$

where c denotes the consumed units of the final good Y, $e^{-\rho(s-t)}$ is the intertemporal consumption discount factor, $\rho > 0$ is the intertemporal preference rate, s is a future date, and $\sigma > 0$. Given the rate of return equal to r, the optimal consumption after maximizing Equation (2.9) is given by:

$$\frac{\dot{C}_t}{C_t} = \frac{1}{\sigma}(r-\rho). \tag{2.10}$$

If $r - \rho > 0$, then household consumption increases over time; if $r - \rho < 0$, household consumption decreases, and if $r - \rho = 0$, consumption remains constant.

Substituting Equation (2.8) into Equation (2.10), it is found that the steady-state consumption growth rate is equal to the product growth rate:

$$g = \frac{1}{\sigma}\left[A^{1/\alpha}\phi F(n^*/N, IDE_{vol}, N/N^*)^{-1}H - \rho\right]. \tag{2.11}$$

As Borensztein, Gregorio and Lee (1998) argue, FDI flows are a good proxy for n^*/N. Considering that $IDE = IDE_{GRF} + IDE_{F\&As}$, Equation (2.11) can be rewritten as:

$$g = \frac{1}{\sigma}\left[A^{1/\alpha}\phi F(IDE_{GRF} + IDE_{F\&As}, IDE_{vol}, N/N^*)^{-1}H - \rho\right]. \tag{2.12}$$

Therefore, the following conclusions can be drawn from Equation (2.12):

1. Both IDE_{GRF} and $IDE_{F\&As}$ reduce the cost of introducing new varieties of capital goods and increase the rate at which these goods are produced since IDE generates spillovers to the domestic economy. It is assumed that the effects of IDE_{GRF} on

growth are greater than the effects of $IDE_{F\&As}$, as Harms and Méon (2018) states that greenfield investment expands the host country's capital and, consequently, deepens its technological structure. On the other hand, F&As generate income for the owner of the acquired company, and such income may not be reinvested. However, this does not mean that $IDE_{F\&As}$ cannot generate spillovers to the domestic economy.

2. The volatility of IDE flows (IDE_{vol}) increases the costs of introducing new technologies and can be understood as a proxy for the economic uncertainty of recipient countries of IDE. Although IDE flows are less volatile than other international capital flows, an increase in the volatility of such flows can have a negative impact on growth.

3. It can be inferred that countries with lower N/N^* are developing countries. Thus, these countries are more prone to imitate technology from MNCs. Therefore, the cost of introducing new capital goods is lower for such countries, and consequently, they will grow faster.

4. Lastly, it is noted that human capital (H) and the macroeconomic and institutional factors of the host country (A) enhance the effects of IDE on economic growth.

To empirically verify the effects of IDE, its two modalities, and volatility on Brazilian economic growth, taking into account this model, the following specifications were used:

$$
\begin{gathered}
CPPC = \alpha_1 IDE + \alpha_2 IDE * A + \alpha_3 IDE * H + \alpha_4 A + \alpha_5 H \\
CPPC = \beta_1 IDE_{GRF} + \beta_2 IDE_{F\&As} + \beta_3 A + \beta_4 H \\
CPPC = \gamma_1 IDE + \gamma_2 IDE_{vol} + \gamma_3 A + \gamma_4 H,
\end{gathered}
\tag{2.13}
$$

where $CPPC$ is the Brazilian GDP growth rate and corresponds to the g of the model, IDE is the foreign direct investment flows and serves as a proxy for n^*/N, H is human capital, A are macroeconomic factors that can enhance the effects of IDE on growth, such factors can be: institutional quality, financial development, among others, IDE greenfield, F&As, and volatility are represented by IDE_{GRF}, $IDE_{F\&As}$, and IDE_{vol}, respectively, and finally, α, β, and γ are parameters to be estimated.

2.4 Empirical Strategy

2.4.1 Econometric Approach

Several models can be used in the macroeconometric context for estimating growth regressions. In this article, we opt for the Vector Autoregressive (VAR) model. This approach is an extension of the univariate autoregressive model and describes the dynamic structure of variables by considering their interdependence. VAR models can be used for forecasting, inference, and policy analysis (ZIVOT; WANG, 2007). It's important to highlight that the variables included in the VAR are determined by economic theory and are usually considered endogenous, which eliminates the problem of simultaneity.

However, the VAR model can have many parameters, making its interpretation challenging due to the complex interactions between variables. Thus, the dynamic properties of a VAR (p) are often summarized using various types of structural analyses (ZIVOT; WANG, 2007).

Consider the following equation:

$$\mathbf{A}\mathbf{Y_t} = \mathbf{B_0} + \sum_{i=1}^{p} \mathbf{B_i}\mathbf{Y_{t-i}} + \mathbf{B}\epsilon_\mathbf{t}, \tag{2.14}$$

where $\mathbf{A}$ is the $n \times n$ matrix of contemporaneous relationships between variables in the $n \times 1$ vector $\mathbf{Y_t}$, $\mathbf{B_0}$ is a $n \times 1$ vector of constants, $\mathbf{B_i}$ is a $n \times n$ matrix of parameters, $\mathbf{B}$ is a diagonal $n \times n$ matrix, and $\epsilon_\mathbf{t}$ is a $n \times 1$ vector of random errors. Equation (2.14) is called a structural VAR (SVAR). This model can be written in the reduced form as:

$$\mathbf{Y_t} = \mathbf{A^{-1}B_0} + \sum_{i=1}^{p} \mathbf{A^{-1}B_i Y_{t-i}} + \mathbf{A^{-1}B}\epsilon_\mathbf{t} = \mathbf{\Phi_0} + \sum_{i=1}^{p} \mathbf{\Phi_i Y_{t-i}} + \mathbf{u_t}, \tag{2.15}$$

here, $\mathbf{A^{-1}B_i} \equiv \mathbf{\Phi_i}$, and:

$$\mathbf{B}\epsilon_\mathbf{t} \equiv \mathbf{A}\mathbf{u_t}, \tag{2.16}$$

where $\mathbf{u_t}$ can be interpreted as orthogonal shocks or innovations. Considering Equation (2.16), three types of restrictions that can be imposed on SVAR according to Lütkepohl (2005):

1. Model A

   In this model, $\mathbf{B} = \mathbf{I_k}$, where k is the number of variables. Therefore, the elements of matrix $\mathbf{A}$ can be estimated.

2. Model B

   Similar to Model A, here $\mathbf{A} = \mathbf{I_k}$. The elements of matrix $\mathbf{B}$ are then estimated.

3. Model AB

   Assuming the model has 4 variables, matrices $\mathbf{A}$ and $\mathbf{B}$ can be written as:

$$\mathbf{A} = \begin{vmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{vmatrix} \qquad \mathbf{B} = \begin{vmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ 0 & 0 & 0 & b_{44} \end{vmatrix}$$

If the diagonal of matrix $\mathbf{A}$ is filled with 1's, the system represented by Equation (2.16) becomes exactly identified. Therefore, in this research, the exactly identified AB-type SVAR was used.[11]

The vector $\mathbf{Y_t}$ consists of the following variables:

- $CPPC$: Brazilian per capita GDP growth rate. This variable is widely used in studies on economic growth, for example, in Carkovic and Levine (2005), Alfaro et al. (2004), Damasceno (2013), among others.

- FDI: Represents the net inflows of foreign direct investment in Brazil divided by GDP. This measure has been used in many studies analyzing the effects of FDI on growth,

[11] This methodology was also used by Kanayo and Emeka (2012), Carminati and Fernandes (2013), Fosu, Bondzie and Okyere (2014), and Bittencourt (2016) to evaluate the impacts of FDI on growth.

such as Alfaro et al. (2004), Carkovic and Levine (2005), Hayat (2019), among others. Its effects on growth are not unanimous in the literature.

- FDI_M where $M \in [GRF, F\&As]$: Represents the value of announced *greenfield* projects and the value of Mergers and Acquisitions (M&A) in Brazil, both divided by GDP. These measures were used by Wang and Wong (2009) and Harms and Méon (2018). The variable FDI_{sint} is also used, which is the sum of *greenfield* FDI and FDI by M&A.[12]

- HC: An index developed by the *Penn World Table* (PWT) that measures the level of Brazilian human capital based on average years of schooling.[13] It is expected to have a positive impact on economic growth. A similar measure was employed by Borensztein, Gregorio and Lee (1998), Alfaro et al. (2004), and Elboiashi (2015).

- DF: An index developed by the International Monetary Fund (IMF) that measures the level of Brazilian financial development. Svirydzenka (2016) argues that this index better captures the complexity of the financial market than other indicators, such as domestic credit provided by the financial sector to the private sector as a percentage of GDP. As it's a relatively new index, its use is not as widespread. However, it can be seen in the work of Sobiech (2019). Its impact on growth is expected to be positive.

- $QINS$: An index measuring the level of institutional quality in Brazil. This variable was constructed using Principal Component Analysis (PCA) of six institutional indicators proposed by Kaufmann, Kraay and Mastruzzi (2011).[14] These indicators measure government effectiveness, democracy, political stability, rule of law, regulatory quality, and control of corruption of countries and range approximately from -2.5 to 2.5. Higher values of this index are associated with better institutional quality. The hypothesis is that countries with higher levels of institutional quality attract larger amounts of FDI,

[12] Announced *greenfield* project value refers to the planned spending on new plants by an investor at the time of announcement. It's worth noting that such investment projects might not be implemented in the year they were announced or could even be canceled. In either of these situations, the announced value of *greenfield* projects would differ from official FDI statistics (UNCTAD, 2019).
[13] This index is calculated by PWT using data from (BARRO; LEE, 2013).
[14] The $QINS$ variable explains 51.15% of the variance of these six institutional indicators.

which in turn tends to be converted into growth. A similar approach was adopted by Adeleke (2014) and Bittencourt (2016).

- $FBCF$: Gross fixed capital formation. This variable is a proxy for domestic investment and includes purchases of machinery and equipment, construction of roads, schools, hospitals, railways, buildings, among others. It is expected that higher domestic investment leads to higher economic growth. This proxy was also used by Alfaro et al. (2004).

- PEA: Brazilian population aged 15 or older who are part of the economically active population. It is expected that a larger labor force (PEA) leads to higher growth. This variable can be found in the research of Vu (2008) and Bittencourt (2016).

- $FDI * X$: FDI multiplied by an interaction variable X. The X can be human capital, institutional quality, or financial development. The hypothesis is that X enhances the positive effects of FDI on growth. Borensztein, Gregorio and Lee (1998), Elboiashi (2015), and Hayat (2019) employed similar methods using interaction variables with FDI.

- $FDI_{vol,i}$ with $i \in (5, 10)$: The moving standard deviation of Brazilian FDI over five and ten periods. The calculation methodology for this variable can be found in Appendix A.4 and was also used by Broto, Díaz-Cassou and Erce (2011).

To achieve the objectives proposed in this research, eight different specifications of SVAR were developed. In the first three specifications, we examined the effects of FDI and interaction variables ($FDI * X$) on Brazilian growth. Each of these three specifications contains one interaction variable. In specifications 4, 5, and 6, we examined the effects of FDI, FDI_{GRF}, and $FDI_{F\&As}$. Finally, in specifications 7 and 8, we analyzed the effects of the volatility of FDI, $FDI_{vol,i}$. Therefore, the specifications are as follows:

- Specification 1: $FDI * HC\ FDI\ PEA\ HC\ FBCF\ CPPC$

- Specification 2: $FDI * QINS\ FDI\ PEA\ HC\ FBCF\ CPPC$

- Specification 3: $FDI * DF\ FDI\ PEA\ HC\ FBCF\ CPPC$
- Specification 4: $FDI_{GRF}\ FDI_{F\&As}\ PEA\ HC\ FBCF\ CPPC$
- Specification 5: $FDI_{sint}\ PEA\ HC\ FBCF\ CPPC$
- Specification 6: $FDI\ PEA\ HC\ FBCF\ CPPC$
- Specification 7: $FDI_{vol5}\ FDI\ PEA\ HC\ FBCF\ CPPC$
- Specification 8: $FDI_{vol10}\ FDI\ PEA\ HC\ FBCF\ CPPC$

To ensure the correct specification of the models, standard procedures for evaluating time series and estimated SVAR models were used. Initially, unit root tests (Augmented Dickey-Fuller Test known as ADF Test) were conducted on the series used. Then, selection criteria for lags were used to determine the appropriate order for each specification.[15] Stability of the specifications at their respective lags was also verified. Finally, autocorrelation tests of the residuals were conducted.[16]

2.5 Results

Initially, we checked the stationarity of the series described in section 2.4.1. For this purpose, the Augmented Dickey-Fuller Test (ADF Test) was used, which can be seen in Table A.2, in Appendix A.2. It can be observed that at the 10% level, only the growth of per capita GDP ($CPPC$), FDI multiplied by institutional quality ($FDI * QINS$), and the ten-period moving standard deviation of FDI (FDI_{vol10}) are stationary. The other variables become stationary after being differenced once.

Next, we used the Akaike Information Criterion (AIC), Schwarz Criterion (SC), and Hannan-Quinn Criterion (HQ) to determine the order of VAR specifications to be estimated. This procedure can be seen in Tables A.3 to A.10 in Appendix A.2. As seen,

15 Akaike Information Criterion (AIC), Schwarz Criterion (SC), and Hannan-Quinn Criterion (HQ).

16 To test the stability of the VAR model, the elements of matrix $\mathbf{B_1}$ in Equation (2.14) are estimated, and their eigenvalues are calculated. If the eigenvalues of $\mathbf{B_1}$ in absolute value are less than one, the VAR is stable.

in Specifications 1 to 6, the chosen lag is two periods. Therefore, Specifications 1 to 6 are VAR(2). In Specifications 7 and 8, the chosen lag is one, i.e., they are VAR(1).

We also verified the stability of the eight estimated Specifications at their respective lags. For this, we used the analysis of the characteristic polynomial roots, which can be seen in Figure A.2. It can be noted that there are no roots outside the unit circle, indicating that the estimated VAR specifications satisfy the stability condition. Finally, using the Lagrange Multiplier (LM) test, we conducted tests for serial autocorrelation in the residuals of the eight estimated specifications. The results, not reported here, indicate the absence of serial autocorrelation.

Having done this, we can analyze the estimation results.[17] First, we examine the effect of FDI and interaction variables on economic growth.[18] The results can be seen in Table 2.1. It can be observed that the estimation results of the coefficients of the matrix of contemporaneous relations correspond to expectations. In other words, the estimated coefficients for Specifications 1, 2, and 3 are all significant at 1% level, and the sign is as expected.[19]

From Table 2.1, it can be noted that FDI considered in isolation has a negative impact on Brazilian growth in Specifications 1 and 2. In Specification 3, the estimated coefficient for FDI is not significant. On the other hand, the effects of interaction variables, $FDI * HC$, $FDI * QINS$, and $FDI * DF$, on Brazilian growth are positive and significant. This indicates that human capital, institutional quality, and financial development enhance the effects of FDI on growth. These results are consistent with the results presented by Fernandes (2006), Mortatti (2011), Carminati and Fernandes (2013), and Bittencourt (2016), who analyzed only the Brazilian case.

It is worth highlighting that, according to Damasceno (2013) and Bittencourt (2016), FDI considered in isolation can have adverse effects on the Brazilian economy, such as financial crises, exchange rate appreciation, trade balance deficits, macroeconomic

17 It's worth noting that in the SVAR model, the coefficients of the matrix of contemporaneous relations are analyzed with the opposite sign of what is obtained in estimation.

18 FDI multiplied by human capital, institutional quality, and financial development, respectively ($FDI * HC$, $FDI * QINS$, and $FDI * DF$).

19 Except for the estimated coefficient of FDI in the third specification.

instability, and concentration of qualified labor by foreign companies.

Table 2.1 – Effects of FDI on Brazilian Economic Growth in Three Specifications of SVAR Model AB

Contemporaneous Relations		Specification 1		Specification 2		Specification 3	
Effect of	On	Coef.	p-value	Coef.	p-value	Coef.	p-value
FDI	$CPPC$	-8.6791	0.0009	-2.1814	0.0000	-1.0567	0.3651
PEA	$CPPC$	3.1699	0.0000	8.2604	0.0000	2.0187	0.0040
HC	$CPPC$	1.7345	0.0000	2.4161	0.0000	1.7377	0.0000
$FBCF$	$CPPC$	1.6708	0.0000	1.8544	0.0000	1.9705	0.0000
$FDI * HC$	$CPPC$	3.9460	0.0000	-	-	-	-
$FDI * QINS$	$CPPC$	-	-	17.7557	0.0000	-	-
$FDI * DF$	$CPPC$	-	-	-	-	0.8432	0.0773

Source: Research results.

Notes: $CPPC$ = per capita GDP growth rate; FDI = foreign direct investment; PEA = economically active population; HC = human capital; $FBCF$ = gross fixed capital formation; $FDI * HC$ = FDI multiplied by human capital; $FDI * QINS$ = FDI multiplied by institutional quality; $FDI * DF$ = FDI multiplied by financial development.

In Specification 4, shown in Table 2.2, we examine the effects of *greenfield* FDI and mergers and acquisitions $FDI_{F\&As}$ on Brazilian growth. It can be observed that the estimated coefficient for FDI_{GRF} is positive and significant at the 1% level, indicating that this investment type has a positive impact on Brazilian economic growth. On the other hand, $FDI_{F\&As}$ has no significant impact. These results are in line with those presented by Wang and Wong (2009) and Harms and Méon (2018), who analyzed sets of developed and developing countries.

Harms and Méon (2018) emphasized that FDI_{GRF} expands the host country's capital and deepens its technological structure. In contrast, $FDI_{F\&As}$ is merely a transfer of ownership that generates income for the owner of the acquired company, and this income may not be reinvested. Also, Filho (2015) pointed out that between 2003 and 2014, Brazil received around 356 billion dollars in FDI_{GRF}, with the majority going to the mining and metallurgy sector, generating 778,000 direct jobs, which may have contributed to the increase in Brazilian economic growth.

In Specification 5, also seen in Table 2.2, the synthetic FDI, FDI_{sint}, which is the sum of $FDI_{F\&As}$ and FDI_{GRF}, is used.[20] Its effect on Brazilian growth is null. In

[20] According Harms and Méon (2018), in theory, one could consider $FDI = FDI_{GRF} + FDI_{F\&As}$.

Specification 6, FDI_{sint} was replaced by FDI. Its effect on Brazilian growth is negative and significant at 1%, similar to Specifications 1 and 2. The coefficients of the other variables, PEA, HC, and $FBCF$, remain significant and positive, indicating their relevance to Brazilian economic growth.

Table 2.2 – Effects of FDI, FDI_{GRF}, and $FDI_{F\&As}$ on Brazilian Economic Growth in Three Specifications of SVAR Model AB

Contemporaneous Relations		Specification 4		Specification 5		Specification 6	
Effect of	On	Coef.	p-value	Coef.	p-value	Coef.	p-value
FDI_{GRF}	$CPPC$	0.6062	0.0000	-	-	-	-
$FDI_{F\&As}$	$CPPC$	0.5475	0.9120	-	-	-	-
PEA	$CPPC$	2.1691	0.0000	2.5622	0.0000	1.8082	0.0005
HC	$CPPC$	1.2220	0.0020	1.6391	0.0000	1.4000	0.0000
$FBCF$	$CPPC$	1.8388	0.0000	1.9380	0.0000	2.0143	0.0000
FDI_{sint}	$CPPC$	-	-	-0.1247	0.5073	-	-
FDI	$CPPC$	-	-	-	-	-0.7062	0.0025

Source: Research results.

Notes: $CPPC$ = per capita GDP growth rate; FDI = foreign direct investment; FDI_{GRF} = foreign direct investment via *greenfield*; $FDI_{F\&As}$ = foreign direct investment via mergers and acquisitions; PEA = economically active population; HC = human capital; $FBCF$ = gross fixed capital formation; FDI_{sint} = synthetic FDI.

Lastly, in Table 2.3, we present the results of Specifications 7 and 8, where the effects of FDI volatility, FDI_{vol}, on Brazilian growth are examined. It can be observed that neither the five-period nor the ten-period volatility had a significant impact on Brazilian growth. This may be attributed to the low volatility of Brazilian FDI during the analyzed period. In fact, FDI is more stable than other international capital flows and may experience declines during economic crises, but to a lesser extent than other investment modalities (CASTRO; CAMPOS, 2018). The estimated coefficients for FDI are also not significant. Additionally, PEA, HC, and $FBCF$ remain significant and positive, indicating their relevance to Brazilian economic growth.

However, this is not borne out in practice. Thus, we chose to create FDI_{sint} and examine its effects on Brazilian economic growth. It's worth noting that this variable is stationary after the first difference.

Table 2.3 – Effects of FDI_{vol} on Brazilian Economic Growth in Three Specifications of SVAR Model AB

Contemporaneous Relations		Specification 7		Specification 8	
Effect of	On	Coef.	p-value	Coef.	p-value
FDI	$CPPC$	0.3418	0.3526	0.6992	0.1213
PEA	$CPPC$	1.4124	0.0204	1.3220	0.0500
HC	$CPPC$	0.5785	0.0464	0.8164	0.0167
$FBCF$	$CPPC$	1.5308	0.0000	1.4646	0.0000
FDI_{vol5}	$CPPC$	-0.4298	0.5777	-	-
FDI_{vol10}	$CPPC$	-	-	-2.2429	0.2981

Source: Research results.

Notes: $CPPC$ = per capita GDP growth rate; FDI = foreign direct investment; PEA = economically active population; HC = human capital; $FBCF$ = gross fixed capital formation; FDI_{vol5} = volatility of FDI over 5 periods; FDI_{vol10} = volatility of FDI over 10 periods.

2.6 Final Remarks

In this paper, we assessed the effects of foreign direct investment (FDI), its volatility (FDI_{vol}), and its two modalities, *greenfield* FDI and mergers and acquisitions (FDI_{GRF} and $FDI_{F\&As}$, respectively), on Brazilian economic growth between the years 1996 and 2018. Additionally, we also examined whether human capital, institutional quality, and the development of the Brazilian financial market contributed to enhancing potential positive effects of FDI on growth. Structural VAR (SVAR) was employed for this purpose.

The findings indicate that FDI considered in isolation does not exert a significant impact on Brazilian economic growth. Inadequate conditions in Brazil may contribute to domestic firms not absorbing potential technology and knowledge spillovers generated by foreign companies. Furthermore, human capital, institutional quality, and financial market development have positive interaction effects with FDI on Brazilian economic growth.

Regarding the two modalities of FDI, *greenfield* FDI (FDI_{GRF}) has a greater capacity to generate economic growth in Brazil compared to mergers and acquisitions ($FDI_{F\&As}$). This is because FDI_{GRF} is directed towards establishing or expanding foreign companies' production capacity within Brazilian territory. Conversely, $FDI_{F\&As}$ represents only a transfer of ownership, and the income from such transfers may not be reinvested. Furthermore, FDI_{GRF} has a greater potential for generating technology and knowledge spillovers to domestic firms compared to $FDI_{F\&As}$, as companies developing new facilities can bring new technologies and skilled labor to the national territory. This is not always the case with $FDI_{F\&As}$.

Lastly, the volatility of Brazilian FDI appears to have no impact on growth. This could be explained by the low volatility of this investment modality in Brazil, which tends to increase during periods of international crises.

3 Misallocation of Talent, Teachers' Human Capital, and development in Brazil

Abstract

In this study, we investigate the allocation of talent in an economy where teachers play a critical role in developing the human capital of the workforce. To this end, we formulate a Roy model with externality in the occupational choice, as the quantity and quality of teachers are key determinants of workers' human capital. Our analysis suggests that when individuals with greater abilities opt for teaching careers, the entire workforce benefits. However, frictions in the labor and educational goods markets may lead to a suboptimal allocation of talent and hinder economic growth and development. Our model is calibrated to the Brazilian economy, and our findings reveal a negative correlation between frictions in the teacher's occupation and per capita output in the Brazilian states. Our results indicate that eliminating friction in the labor market could result in a 16.94% increase in Brazilian income.
Keywords: Misallocation; Human Capital; Labor; Externalities; Growth.

3.1 Introduction

Many studies analyze the hindrances to economic growth, and one relevant approach is that of resources misallocation. Misallocation of capital, credit, and talent has been pointed out as possible barriers to growth (BANERJEE; DUFLO, 2005; RESTUCCIA; ROGERSON, 2008; HSIEH; KLENOW, 2009; HSIEH et al., 2019). Misallocation of talent across occupations and sectors may be a consequence of race and gender discrimination, social norms and culture, and barriers to the human capital formation (RESTUCCIA; ROGERSON, 2017).[1] In the present paper, we study the allocation of talent in an economy where individuals choose their occupation facing different barriers among professions, and teachers play an explicit role in the human capital formation of all workers.

Based on Hsieh et al. (2019), we build a general equilibrium model where individuals choose consumption, time at school, investment in education, and the sector to work. We introduce two barriers that influence individuals' occupational choices, affecting talent allocation in the economy. First, we consider frictions in the labor market, which can be interpreted as the relative difficulty of finding a job in a given occupation and region. This barrier can result from social status or discrimination. The second barrier appears in the educational market. It is related to the costs of human capital formation in a given region and occupation.

In our model, the number of workers choosing an occupation decreases with higher barriers. Moreover, frictions in the teacher's occupation would harm the whole economy since it is essential to the human capital formation of all workers. Furthermore, following Eckstein and Zilcha (1994), we consider the quality of teachers as an input to human capital formation. Based on Gilpin and Kaganovich (2012) and Hatsor (2012), we also consider the number of teachers as input.

Our model is calibrated to the Brazilian economy, where our baseline calibration demonstrates a positive correlation between barriers to the teacher's occupation and per

[1] In the context of developing economies, Hnatkovska, Lahiri and Paul (2012) show that the misallocation of talent in India comes from the caste system. In Brazil, Café (2018) shows an overqualification of workers in the public sector in relation to the private sector, especially when the evaluation in the public sector is not related to the worker's performance.

capita output in the Brazilian states. Specifically, these barriers are lower in the less developed regions of Brazil, leading to the accumulation of more human capital among teachers in these areas. Conversely, the more developed states exhibit higher levels of productivity, owing to elevated Total Factor Productivity (TFP).

Brazil confronts several microeconomic challenges, such as a distortionary tax burden, high levels of labor market regulation with expensive firing costs, varying regulations across different sectors, different levels of union market power across sectors, limited competition in several industries (like the energy sector), regional disparities in infrastructure quality, and a significant informal sector. These obstacles make Brazil an important country for research and analysis.

Barros and Delalilbera (2018) have also identified an inverse relationship between the relative wage of teachers and the Brazilian states' economic development. They point out that the occupational choice of workers with multiple skills is driven by labor market incentives (net wage) and the costs of investing in education. Our study differs from Barros and Delalilbera (2018) in two ways. First, in addition to considering that teachers' human capital is a source of positive externalities, we explicitly model the importance of the number of teachers in the workforce's human capital formation. Second, we use our model to study differentials in the relative workers' wages to better understand the relationship between market frictions and the misallocation of talent in Brazil.

We show that the frictions related to the teacher's occupation have a more relevant influence on the economy's output than those of other occupations. We run a series of counterfactual exercises, and we find that the complete removal of frictions in the Brazilian economy would generate an increase of 16.94% in GDP. Furthermore, we calibrate our model with data from different periods to study the evolution of the allocation of talent in Brazil. We argue that the reduction of the barriers over time could be one of the drivers of absolute income convergence across the Brazilian states.[2]

Although we based our model on Hsieh et al. (2019), we are interested in understanding the impact of misallocation of talent in the teacher's occupations. In contrast,

[2] See Ferreira (2000) and Ribeiro and Almeida (2012) for evidence of income convergence in Brazil.

Hsieh et al. (2019) study the economic performance related to the reduction in gender and race discrimination over time in the United States. They find that between 20% and 40% of GDP per capita growth over the last five decades is due to declining occupational barriers, causing women and blacks to occupy highly qualified positions over time. Abdulla (2019) also investigates the misallocation of talent in Brazil and India. Their results show that removing all frictions of the labor market and human capital accumulation in Brazil and India would increase average output by 22–52% and 38–53%, respectively. We extend the analysis of the above studies by modeling the tradeoff between quality and quantity of teachers in human capital formation.

The misallocation literature has traditionally focused on the role of individual choices in explaining the economic outcome. However, recent studies have highlighted the importance of financial constraints in shaping the educational choices of families (SOARES; KRUGER; BERTHELON, 2012; PONCZEK; SOUZA, 2012; HANUSHEK; LEUNG; YILMAZ, 2014; DELALIBERA; FERREIRA, 2019; BROTHERHOOD; DELALIBERA, 2020). For example, Soares, Kruger and Berthelon (2012) provide micro-evidence that children from disadvantaged families are associated with more child labor and less schooling, while Ponczek and Souza (2012) shows that twins in the family have adverse consequences for children's education. Hanushek, Leung and Yilmaz (2014) provide an overlapping generations model that demonstrates how different college funding rules can affect aggregate outcomes and individual welfare. Brotherhood and Delalibera (2020) also build an overlapping generation model to study the optimal allocation of public expenditure across schools and universities.[3] Our findings complement this literature by studying how barriers in educational markets, which can also be viewed in part as financial constraints, can affect the occupational choice of multi-ability workers and generate a misallocation of talent.

Human capital is crucial for economic development by increasing labor productivity, besides facilitating innovation and diffusion of technology as in Romer (1990),

[3] In this context, Brotherhood, Delalibera and Pereira (2022) claim that when there is a high proportion of credit-constrained students, a reallocation of expenditure towards public schools positively affects GDP.

Mankiw, Romer and Weil (1992), Borensztein, Gregorio and Lee (1998), and Benhabib and Spiegel (2005). We contribute to this literature by showing how regional disparities in the labor and educational markets can generate talent misallocation in the teacher's occupation and, in turn, affect aggregate human capital.

The recent literature has emphasized the relevance of education quality in economic growth. For example, Hanushek and Woessmann (2012) argue that Latin American countries lagged behind because of their students' poor performance in educational achievement. In addition, many studies point to the relevance of teachers in the students' learning process (WOESSMANN, 2016; BARROS; DELALILBERA, 2018; HANUSHEK; PIOPIUNIK; WIEDERHOLD, 2019). Indeed, Hanushek, Piopiunik and Wiederhold (2019) find a robust and positive relationship between the teachers' cognitive skills and student performance measured by the Programme for International Student Assessment (PISA) scores. The cognitive skills of teachers are even more critical to students' performance than the cognitive skills of their parents (HANUSHEK; PIOPIUNIK; WIEDERHOLD, 2019).

Using the PISA's mathematics test score, Woessmann (2016) points to the relevance of teachers' quality measured by their relative wage and human capital on students' performance. Woessmann (2016) argues that higher teacher wages positively influence recruiting higher-ability individuals into teaching. For Brazil, Menezes-Filho and Pazello (2007) find that the relative wage of teachers positively affects the proficiency of public school students. Machado and Scorzafave (2016) point out that wages may affect the decision of the most talented individuals to become teachers. In addition, after an individual becomes a teacher, the wages affect their effort in the classroom and the turnover rate. Several other studies also indicate that the ability of teachers is related to their relative wage, as Stoddard (2003), Lakdawalla (2006), and Bacolod (2007).

Tamura (2001) examines the role of education and the quality and quantity of teachers in economic growth and income convergence. Following Card and Krueger (1992a) and Card and Krueger (1992b), Tamura (2001) formulates a function of human capital formation, where teachers' quality and class size interact with private investment to produce human capital. Then, the author shows that human capital convergence across regions occurs if teachers' quality is relatively more important than class size in human capital production. He argues that poor school districts have relatively better teachers than wealthier districts, driving the income convergence observed in the data. We also consider teachers' quality and quantity to study income convergence across the Brazilian states. We find that income convergence is due to human capital convergence because teachers of poorer Brazilian states have a higher quality.

Besides this introduction, the present paper is organized as follows. Section 3.2 presents our general equilibrium model. Section 3.3 explains how this model is calibrated using data from the Brazilian economy. The calibration results, some stylized facts, and the counterfactual exercises are presented in Section 3.4. Section 3.5 presents the robustness checks of our main exercises. Finally, Section 3.6 brings our final remarks.

3.2 Model

This section provides an overview of the model and its fundamental assumptions. We discuss the behavior of both firms and workers and highlight the main implications of the model. Additionally, we define the competitive equilibrium.

3.2.1 Firms

We begin by considering a country divided into $R \in \mathbb{N}$ independent regions (states). Each region comprises a continuum of workers who choose one of the $N \in \mathbb{N}$ available occupations in the economy. It is assumed that workers born in a particular region, r, can only work there.[4] Multiple homogeneous competitive firms hire workers from all regions and occupations to produce a single product. The production function for each firm is defined by

$$Y = \sum_{r=1}^{R} \sum_{i=1}^{N} A_r H_{ir}, \tag{3.1}$$

[4] In Appendix B.4, we discuss migration and argue that the fraction of the Brazilian population that migrates is relatively small. Therefore, our assumption of no migration is consistent with the available data.

where Y is output, A_r is Total Factor Productivity (TFP) of region r, and H_{ir} is the aggregate human capital of people working in occupation i at region r. Output can be consumed or used as an educational good. The firm's problem is choosing labor in terms of efficient units (aggregate human capital) to maximize profit, taking wages (w_{ir}) of each occupation in each region as given.

$$\max_{H_{ir}\geq 0}\left[\sum_{r=1}^{R}\sum_{i=1}^{N}A_rH_{ir}-\sum_{r=1}^{R}\sum_{i=1}^{N}w_{ir}H_{ir}\right]. \tag{3.2}$$

The solution to the problem described above is simple. The demand for human capital is given by:

$$H_{ir}^d=\begin{cases}0 & \text{if } A_r<w_{ir}\\ x\in\mathbb{R}_+ & \text{if } A_r=w_{ir}\\ \infty & \text{if } A_r>w_{ir}\end{cases}. \tag{3.3}$$

3.2.2 Workers

Each worker in our model has idiosyncratic abilities for each occupation. In a world with multiple occupations, some workers possess a high talent for many occupations, while others may lack the skills for any occupation. Individuals value both consumption and leisure, which we model as the time not spent at school. Each worker is endowed with one unit of time, which can be allocated to either studying or leisure. The following equation gives the utility of a worker:

$$U(c,s)=c^{\beta}(1-s), \tag{3.4}$$

where c represents consumption, s is time spent at school, and β is a parameter giving the relative importance of consumption to leisure.

We adopt the approach of Hsieh et al. (2019) and introduce two frictions in our model. First, we assume that a person working in occupation i in region r is paid a net wage of $(1-\tau_{ir}^w)w_{ir}$, where τ_{ir}^w is a barrier specific to occupation i and location r. This can be interpreted as an unobserved cost (or benefit) of working in occupation i at region

r, which can arise due to various factors such as social status or barriers to finding a job in a given occupation and region.

The educational market in our model also experiences friction in the form of τ_{ir}^h, which captures the barriers to acquiring human capital for different occupations and regions. These barriers may include difficulties in finding quality educational institutions or suitable training programs for a particular occupation. Additionally, τ_{ir}^h may represent the costs of developing the necessary skills for specific occupations.

Following Tamura (2001) and Barros and Delalilbera (2018), we assume that the quality of teachers is a crucial input to human capital formation. In addition, we extend the existing literature by incorporating the number of teachers as a determinant of workers' human capital formation. Therefore, the human capital of workers in each region can be represented by the following expression:

$$h_{ir}(e,s) = T_r^{\varphi} s_i^{\phi_i} e_{ir}^{\eta}, \tag{3.5}$$

Where e represents the consumption of educational goods, s is the time spent at school, η is the elasticity of the human capital concerning the consumption of educational goods, and $\phi_i > 0$ is the elasticity of human capital concerning the time spent at school. This parameter varies among occupations and generates differences in schooling. Finally, T_r represents the role of teachers in the workers' human capital formation. We set $T_r = p_{tr}^{\alpha} H_{tr}^{1-\alpha}$ where $\alpha \in (0,1)$, p_{tr} is the fraction of people working as teachers, and H_{tr} is the teachers' aggregate human capital. We use this functional form to incorporate the quality and quantity of teachers into the workers' human capital formation.[5]

Following McFadden (1974), Eaton and Kortum (2002), and Hsieh et al. (2019), abilities dispersion is modeled as a multivariate Fréchet distribution. Let ϵ_i be the ability of an individual in occupation i, then the distribution of abilities across occupations is:

$$F(\epsilon_1, \ldots, \epsilon_N) = \exp\left[-\sum_{i=1}^{N} \epsilon_i^{-\theta}\right], \tag{3.6}$$

where θ governs the skill dispersion.

[5] See Krueger (2003) and Lakdawalla (2006) for a discussion on teachers' quality and quantity.

The individual decision is made in two steps. First, given the occupational choice i, for which the individual has an idiosyncratic ability ϵ_i, and taking wage w_{ir} as given, each worker chooses c, e, and s, to solve the following problem:

$$\max_{c,s,e} c^{\beta}(1-s) \tag{3.7}$$
$$\text{s.t. } c = (1-\tau_{ir}^{w})w_{ir}h_{ir}(e_{ir}, s_i)\epsilon_i - (1+\tau_{ir}^{h})e_{ir},$$

Solving the problem above yields the optimal time spent on school and the amount of educational goods purchased:[6]

$$s_i^* = \left(1 + \frac{1-\eta}{\beta\phi_i}\right)^{-1} \tag{3.8}$$
$$e_{ir}^*(\epsilon) = \left[\eta\left(\frac{1-\tau_{ir}^{w}}{1+\tau_{ir}^{h}}w_{ir}\right)(p_{tr}^{\alpha}H_{tr}^{1-\alpha})^{\varphi}\left(1+\frac{1-\eta}{\beta\phi_i}\right)^{-\phi_i}\epsilon_i\right]^{\kappa} \tag{3.9}$$

where $\kappa = 1/(1-\eta)$.

A higher elasticity of human capital with respect to time for a given occupation (ϕ_i) leads to more time allocated to human capital accumulation. Individuals in occupations with a high ϕ_i acquire more schooling and have higher wages as compensation.

Using equations (3.8), (3.9) and the budget constraint into the utility function, we have the following indirect utility function for occupation i:

$$D_{ir} = \left[\bar{\eta}\left(\frac{1-\tau_{ir}^{w}}{(1+\tau_{ir}^{h})^{\eta}}w_{ir}\right)(p_{tr}^{\alpha}H_{tr}^{1-\alpha})^{\varphi}s_i^{\phi_i}(1-s_i)^{\frac{1}{\beta\kappa}}\epsilon_i\right]^{\beta\kappa} \tag{3.10}$$

where $\bar{\eta} = \eta^{\eta}(1-\eta)^{1-\eta}$.

Therefore, the occupational choice problem reduces to picking the occupation that delivers the highest D_{ir}.[7] Since talent is drawn from an extreme value distribution, the highest utility can also be characterized by an extreme value distribution (MCFADDEN, 1974). Proposition 1 states that the share of the workers in each occupation can be obtained by aggregating the individuals' optimal choices.

[6] For a complete solution of the model, refer to the Online Appendix.

[7] Our model assumes a deterministic path for every feasible occupational choice without inherent risk. Additionally, we assume that there is no variation in the pre-existing wealth of workers. However, empirical evidence suggests that less wealthy individuals tend to select less risky income paths due to the higher marginal utility of consumption (GUO; LEUNG, 2021). For example, Cagetti and Nardi (2006) find that restrictive borrowing constraints reduce the number of people engaging in (risky) entrepreneurial activities.

Proposition 1 (Occupational choice)**.** *Let p_{ir} be the fraction of workers in occupation i in region r. Then, aggregating the solution of individual's occupational choice problem across workers, we have:*

$$p_{ir} = \frac{\tilde{w}_{ir}^{\theta}}{\sum_{j=1}^{N} \tilde{w}_{jr}^{\theta}} \tag{3.11}$$

where

$$\tilde{w}_{ir} = \bar{\eta} \left(\frac{1-\tau_{ir}^{w}}{(1+\tau_{ir}^{h})^{\eta}} w_{ir} \right) (p_{tr}^{\alpha} H_{tr}^{1-\alpha})^{\varphi} s_i^{\phi_i} (1-s_i)^{\frac{1}{\beta\kappa}}$$

Proof. Let:

$$\tilde{w}_{ir} = \bar{\eta} \left(\frac{1-\tau_{ir}^{w}}{(1+\tau_{ir}^{h})^{\eta}} w_{ir} \right) (p_{tr}^{\alpha} H_{tr}^{1-\alpha})^{\varphi} s_i^{\phi_i} (1-s_i)^{\frac{1}{\beta\kappa}}$$

Then, we can rewrite equation (3.10) as:

$$D_{ir} = [\tilde{w}_{ir}\epsilon_i]^{\beta\kappa}$$

Therefore, the individual decision problem for worker i in region r consists of choosing the occupation that yields the highest value of $\tilde{w}_{ir}\epsilon_i$. Without loss of generality, let us consider the probability of an individual choosing occupation 1:

$$\begin{aligned} p_{ir} &= Pr(\tilde{w}_{1r}\epsilon_1 > \tilde{w}_{ir}\epsilon_i) \quad \forall\, i \neq 1 \\ &= Pr\left(\epsilon_i < \frac{\tilde{w}_{1r}}{\tilde{w}_{ir}}\epsilon_1\right) \quad \forall\, i \neq 1 \\ &= \int F_1(\alpha_1\epsilon, \alpha_2\epsilon, ..., \alpha_N\epsilon) d\epsilon \end{aligned} \tag{3.12}$$

where F_1 represents the derivative of equation (3.6) with respect to its first argument, and $\alpha_i = \tilde{w}_{1r}/\tilde{w}_{ir}$ for $i \in \{1, 2, ...N\}$. Taking the derivative of equation (3.6) with respect to ϵ_1, and evaluating in ϵ:

$$\begin{aligned} F_1 &= \theta\epsilon_1^{-\theta-1} \exp\left(-\epsilon_1 \hat{Z}\right) \\ F_1(\epsilon) &= \theta\epsilon^{-\theta-1} \exp\left(-\epsilon \hat{Z}\right) \end{aligned}$$

where $\hat{Z} = \sum_{i=1}^{n} \alpha_i^{-\theta}$. Then, equation (3.12) can be written as:

$$\begin{aligned} p_{1r} &= \int \frac{\hat{Z}}{\hat{Z}} \theta\epsilon^{-\theta-1} \exp\left(-\epsilon^{-\theta}\hat{Z}\right) d\epsilon \\ &= \frac{1}{\hat{Z}} \int \hat{Z}\theta\epsilon^{-\theta-1} \exp\left(-\epsilon^{-\theta}\hat{Z}\right) d\epsilon \end{aligned}$$

This expression is the derivative of equation (3.6) with respect to ϵ. Hence:

$$\begin{aligned} p_{1r} &= \frac{1}{\hat{Z}} \int dF(\epsilon) \\ &= \frac{1}{\hat{Z}} \\ &= \frac{\tilde{w}_{1r}^{\theta}}{\sum_{i=1}^{N} \tilde{w}_{ir}^{\theta}} \end{aligned}$$

□

We can interpret $\tilde{w}_{ir}$ as a net reward of a person from region r and occupation i with average ability. Therefore, $\tilde{w}_{ir}$ is composed of wage per efficiency unit, schooling, teachers' human capital, and barriers. In this context, occupations with high w_i will attract more workers in all regions. On the other hand, differences in occupational choices are driven by frictions in the educational goods and labor markets. Therefore, the fraction of individuals choosing sector i is low when there are considerable barriers in human capital formation (τ^h is high) and in the labor market (τ^w is high). The following proposition defines the workers' human capital in each occupation in a given region.

Proposition 2 (Average quality of workers)**.** *For a given region, the human capital of workers in occupation i is:*

$$H_{ir} = p_{ir}\mathbb{E}[h(e_{ir}, s_i)\epsilon_i | person\ choices\ i], \tag{3.13}$$

The average quality of workers is:

$$\mathbb{E}[h(e_{ir}, s_i)\epsilon_i | person\ choices\ i] = \bar{\Gamma} \left[\left(\frac{1-\tau_{ir}^{w}}{1+\tau_{ir}^{h}} w_{ir} \right)^{\eta} \tilde{h}_{ir} p_{ir}^{-\frac{1}{\theta}} \right]^{\kappa} \tag{3.14}$$

where $\bar{\Gamma} = \Gamma(1-\kappa/\theta)$ *is related to the mean of the Fréchet distribution for abilities,* $\tilde{h}_{ir} = [(p_{tr}^{\alpha} H_{tr}^{1-\alpha})^{\varphi} s_i^{\phi_i} \eta^{\eta}]^{\kappa}$ *and* $\kappa = 1/(1-\eta)$.

Proof. We have:

$$h(e_{ir}, s_i)\epsilon_i = (p_{tr}^{\alpha} H_{tr}^{1-\alpha})^{\varphi} \left[\eta \left(\frac{1-\tau_{ir}^{w}}{1+\tau_{ir}^{h}} w_{ir} \right) (p_{tr}^{\alpha} H_{tr}^{1-\alpha})^{\varphi} s_i^{\phi} \epsilon_i \right]^{\eta\kappa} s_i^{\phi_i} \epsilon_i \tag{3.15}$$

H_{ir} is the total labor supply in efficiency units of occupation i in region r. Then,

$$\begin{aligned}
H_{ir} &= p_{ir}\mathbb{E}\left\{(p_{tr}^{\alpha}H_{tr}^{1-\alpha})^{\varphi}\left[\eta\left(\frac{1-\tau_{ir}^{w}}{1+\tau_{ir}^{h}}w_{ir}\right)(p_{tr}^{\alpha}H_{tr}^{1-\alpha})^{\varphi}s_i^{\phi_i}\epsilon_i\right]^{\eta\kappa} s_i^{\phi_i}\epsilon_i \middle| \text{person choices } i\right\} \\
&= p_{ir}\left\{(p_{tr}^{\alpha}H_{tr}^{1-\alpha})^{\varphi}\left[\left(\frac{1-\tau_{ir}^{w}}{1+\tau_{ir}^{h}}w_{ir}\right)\eta(p_{tr}^{\alpha}H_{tr}^{1-\alpha})^{\varphi}s_i^{\phi_i}\right]^{\eta\kappa} s_i^{\phi_i}\mathbb{E}\left[\epsilon_i^{\kappa}\middle| \text{person choices } i\right]\right\} \\
&= p_{ir}\tilde{h}_{ir}\left(\frac{1-\tau_{ir}^{w}}{1+\tau_{ir}^{h}}w_{ir}\right)^{\eta\kappa}\mathbb{E}\left[\epsilon_i^{\kappa}\middle| \text{person choices } i\right] \qquad (3.16)
\end{aligned}$$

To calculate this last conditional expectation, we use the Fréchet distribution. We suppress the region index r because this calculation is similar across all regions. Let $y_i = \tilde{w}_i\epsilon_i$. Since we are maximizing y_i, it also has the extreme value distribution:

$$\begin{aligned}
\mathbf{Pr}\left(\operatorname*{Max}_i y_i < z\right) &= \mathbf{Pr}(\epsilon_i < z/\tilde{w}_i) \quad \forall i \\
&= F(z/\tilde{w}_1, ..., z/\tilde{w}_N) \\
&= \exp\left[-\sum_{i=1}^{N}(z/\tilde{w}_i)^{-\theta}\right] \\
&= \exp\left[-kz^{-\theta}\right]
\end{aligned}$$

where $k = \sum_i^N \tilde{w}_i^{\theta}$.

After some algebraic manipulation, we conclude that the distribution of ϵ^* (the workers' ability in their chosen occupation) has a Fréchet distribution:

$$G(x) = \mathbf{Pr}(\epsilon^* < x) = \exp\left[-k^* x^{-\theta}\right] \qquad (3.17)$$

where $k^* = \sum_{i=1}^{N}(\tilde{w}_i/\tilde{w}^*)^{\theta} = 1/p^*$.

Finally, we calculate the expectation of equation (3.16). Let i be the occupation an individual chooses, and λ a positive exponent.

$$\begin{aligned}
\mathbb{E}(\epsilon_i^{\lambda}) &= \int_0^{\infty}\epsilon_i^{\lambda}dG(\epsilon) \\
&= \int_0^{\infty}\theta\left(\frac{1}{p^*}\right)\epsilon^{(\lambda-\theta-1)}\exp\left[\left(\frac{1}{p^*}\right)\epsilon^{-\theta}\right]d\epsilon
\end{aligned}$$

We set $x = \left(\frac{1}{p^*}\right)\epsilon^{-\theta}$ and rewrite the last expression as:

$$
\begin{aligned}
\mathbb{E}(\epsilon_i^{\lambda}) &= \left(\frac{1}{p^*}\right)^{\frac{\lambda}{\theta}} \int_0^{\infty} x^{-\frac{\lambda}{\theta}} \exp(-x) dx \\
&= \left(\frac{1}{p^*}\right)^{\frac{\lambda}{\theta}} \Gamma\left(1 - \frac{\lambda}{\theta}\right)
\end{aligned}
$$

Using this result in equation (3.16) completes the proof. □

This finding suggests that there is a selection effect at play in the economy. Equation (3.14) reveals that the average quality of workers in occupation i and region r is inversely related to the proportion of workers in that occupation (p_{ir}). When there are significant frictions in occupation i and region r, only the most skilled workers are selected for that occupation. For example, if becoming a teacher is relatively easy in a particular region, the average human capital of teachers in that region will be low (intensive margin). On the other hand, if we keep the average human capital constant and increase the proportion of workers in an occupation, the aggregate human capital will be higher (extensive margin). The net effect depends on the values of the parameters. When $\theta(1-\eta) > 1$, the extensive margin dominates, while the intensive margin dominates otherwise. Having established this, we solve the model for the average wage in occupation i and region r.

Corollary 3.2.0.1 (Gross average wages)**.** *Let W_{ir} be the gross average wage in occupation i in region r. Then:*

$$
W_{ir} = w_{ir}\mathbb{E}[h(e_{ir}, s_i)\epsilon_i] = \bar{\Gamma}\eta \frac{(1-s_i)^{-1/\beta}}{(1-\tau_{ir}^{w})} \left(\sum_{i=1}^{N} \tilde{w}_{ir}^{\theta}\right)^{\frac{\kappa}{\theta}} \tag{3.18}
$$

This result is a consequence of Proposition 2. As equation (3.18) indicates, the gross average wage varies across occupations in a region due to differences in schooling and labor market frictions. Occupations with higher levels of human capital offer more substantial gross average wages. Using equation (3.3), we deduce that in equilibrium, $A_r = w_{ir}$. As a result, $\tilde{w}ir$ is a function of A_r, and consequently, Wir depends on regional TFP. This implies that labor market frictions, average human capital, and TFP are all critical determinants of regional average wage disparities. Finally, we adopt a standard competitive equilibrium definition.

3.2.3 Equilibrium

Definition 1 (Competitive equilibrium). *A competitive equilibrium in this economy consists of:*

1. *Given an occupational choice, w_{ir}, and the idiosyncratic ability ϵ, each worker chooses c, e, s to maximize utility in equation* (3.7).
2. *Given market friction, w_{ir}, H_{it}, and ϵ, a worker chooses the occupation that maximizes D_{ir}.*
3. *A representative firm hires H_{ir} to maximize profits.*
4. *The occupational wage, w_{ir}, clears the labor market in each occupation and region.*
5. *Total output is given by the production function in equation* (3.1).

3.3 Empirical Investigation

This section describes how we calibrated the model to fit the Brazilian data. We used data from two distinct periods (2003 and 2015) to investigate the convergence of income and human capital across the Brazilian states.[8]

Our calibration strategy involved identifying appropriate values for frictions and TFP to ensure that the competitive equilibrium is consistent with the dataset of the Brazilian states in 2015. To achieve this goal, we used individual-level data from the Brazilian National Household Sample Survey (PNAD) for the following variables: years of schooling; work hours; gross earnings; and the share of workers in occupations.

After some adjustments,[9] our dataset consisted of 109,038 individuals belonging to

[8] We chose this period because the Brazilian National Household Sample Survey (PNAD) methodology underwent changes before 2003 and after 2015.

[9] We removed individuals with no occupation and those whose wages were less than 60% of the minimum wage to eliminate cases of underreported wages, leading us to drop individuals receiving considerably less than the minimum wage. We also limited our sample to individuals between the ages of 25 and 65, and excluded individuals in occupations that were not well-defined or in the military. In Appendix B.5, we present the results of an alternative calibration of our model, which demonstrates the robustness of our results to the data filtering process, including individuals that earn less than 60% of the minimum wage.

eight occupational groups: 1) managers (excluding those in the public sector); 2) professionals in the fields of science and the arts; 3) middle-level technicians; 4) administrative service workers; 5) individuals in the service sector; 6) professionals in sales and service provision; 7) agricultural workers; and 8) workers in the goods and industrial production, services, and repairs/maintenance. To simplify our analysis, we combined groups 4, 5, and 6 into the service sector. Additionally, we separated individuals working as teachers in another category, resulting in the following list of occupational categories:

1. Managers (except public sector);
2. Professionals of sciences and arts (except teachers);
3. Middle-level technicians (except teachers);
4. Service sector;
5. Agriculture;
6. Goods and industrial production, services and repairs-maintenance;
7. Teachers.

The 26 Brazilian states and the Federal District (DF) are considered in the empirical analysis.[10] Therefore, the dataset contains a total of seven different occupations ($N = 7$) spread across twenty-seven regions ($R = 27$).

We divided the parameters into three distinct groups. The first group contains the preferences and technology parameters (η, θ, φ, β, α). The second group consists of the elasticity of human capital in relation to time spent at school (ϕ_i), as well as the frictions (τ_{ir}^{w} and τ_{ir}^{h}). The third group includes TPF (A_r).

[10] Acre (AC), Alagoas (AL), Amapá (AP), Amazonas (AM), Bahia (BA), Ceará (CE), Espírito Santo (ES), Goiás (GO), Maranhão (MA), Mato Grosso (MT), Mato Grosso do Sul (MS), Minas Gerais (MG), Pará (PA), Paraíba (PB), Paraná (PR), Pernambuco (PE), Piauí (PI), Rio de Janeiro (RJ), Rio Grande do Norte (RN), Rio Grande do Sul (RS), Rondônia (RO), Roraima (RR), Santa Catarina (SC), São Paulo (SP), Sergipe (SE), Tocantins (TO).

3.3.1 Preferences and Technology Parameters

The model's parameters define the functional forms of various equations, such as those governing the distribution of abilities and the utility function. We set the first group of parameters (η, θ, φ, β, α) to evaluate income convergence by taking the mean of specific statistics from the period between 2003 and 2015. To estimate the skill dispersion parameter (θ) and the elasticity of human capital to educational goods (η), we follow the approach of Hsieh et al. (2019). We assume that wages within a specific occupation and region follow a Fréchet distribution shaped by θ and η in a multiplicative form: $\theta(1-\eta)$. Therefore, the dispersion of wages depends on $1/\theta$ and $1/(1-\eta)$, and the coefficient of variation (CV) of wages within a particular occupation and region is given by:

$$CV = \frac{\Gamma\left(1 - \frac{2}{\theta(1-\eta)}\right)}{\left(\Gamma\left(1 - \frac{1}{\theta(1-\eta)}\right)\right)^2} - 1, \tag{3.19}$$

where γ represents the Gamma function.

Afterward, we compute the mean and variance of the exponent of the regression residuals and use a root-finding algorithm to solve equation (3.19) for $\theta(1-\eta)$. The value for 2003 is 2.39, for 2015 it is 2.00, and the average of the two years is 2.19.

We adopt the approach of Hsieh et al. (2019) to estimate η as the ratio of educational expenditure to labor compensation. The total amount of public and private educational expenditures as a share of GDP was 0.064 in 2003, 0.079 in 2015, and its average was 0.072. The ratio of labor compensation to GDP was 0.53 in 2003, 0.58 in 2015, and averaged 0.56.[11] We set η to 0.129 based on these values. With $\theta(1-\eta)$ and η in hand, we can easily compute θ as 2.52.

Table 3.1 presents the remaining functional parameters of the model. To specify the parameters related to the teacher's role in human capital formation, we adopt the values suggested by Tamura (2001): $\alpha = 0.31$; and $\varphi = 0.48$. We also set $\beta = 0.231$, following Hsieh et al. (2019). In Section 3.5, we investigate the robustness of our results by varying the values of α, β, θ, η, and φ.

[11] The data for labor compensation as a share of GDP was obtained from the Penn World Table 10.0.

Table 3.1 – Baseline constant parameters

Parameters	Value	Description	Source
η	0.129	Elasticity of educational goods in the human capital function	Estimated using data from PNAD 2015 and 2003
φ	0.48	Elasticity of teacher's human capital in the human capital function	(TAMURA, 2001)
θ	2.52	Dispersion of skills	Estimated using data from PNAD 2015 and 2003
α	0.31	Weight of the share of teachers in T_r	(TAMURA, 2001)
β	0.231	Consumption preference	hsie2019

3.3.2 Estimation of ϕ_i's

To calculate the second group of parameters, which represents the elasticity of human capital to time spent at school for each occupation (ϕ_i's), we begin by computing the average years of schooling for each occupation and then the study hours. We assume that a typical individual studies six hours a day on weekdays, so the number of study hours in a year is $252 \times 6 = 1512$. Therefore, of the 8760 hours available in a year, the time studying represents 17.26%.

We assume that the schooling period occurs in the first 25 years of an individual's life, which is the upper bound of years of education in our model. We then divide the average years of schooling in the dataset by 25 and multiply it by the share of studying time in a year (0.1726). Finally, we use equation (3.8) to calculate the ϕ_i's.[12] Table 3.2 brings the results.

Table 3.2 – Descriptive statistics of years of schooling among occupations and implied ϕ

	Parameter	Schooling Statistics				
Occupation	ϕ_i	Mean	1° Quartile	Median	3° Quartile	Variance
Managers	0.28	11.77	11	11	15	3.36
Sciences and arts	0.35	13.98	15	15	15	2.39
Middle-level technicians	0.28	11.67	11	11	14	2.58
Service-sector	0.22	8.91	6	11	11	3.79
Agriculture	0.12	5.07	2	4	8	3.92
Industrial production and services	0.18	7.75	5	8	11	3.69
Teachers	0.35	14.13	14	15	15	1.69

Source: Elaborated by the authors with data from PNAD 2015. Each ϕ_i is computed using equation (3.8).

[12] By rewriting Equation (3.8) as $\phi_i = \dfrac{(1-\eta)s_i}{\beta(1-s_i)}$, we can substitute the time spent on education, as calculated previously, and the other parameters into this expression.

3.3.3 Calibration of $\tau's$ and $A's$

We calibrate the remaining parameters, τ's and A's, using the Method of Moments, which involves minimizing the difference between the statistics of our model and those of the Brazilian data. In the calibration procedure, we use two statistics groups for each occupation and region: the workers' share; and the average gross wage.

We utilize the PNAD microdata to compute the average hourly wage for each occupation in each region.[13] In our model, those statistics are described by equations (3.11) and (3.18). We use the First Order Conditions (FOC) of the firm's maximization problem, where $w_{i,r} = A_r \, \forall \, i, r$, to recover the equilibrium wage rate, which allows us to use equations (3.11) and (3.18) to compute the model's statistics that represents the competitive equilibrium.

The sum of the occupations' share in each region equals one, $\sum_{i=1}^{N} p_{ir} = 1$, implying that each region has $(N-1)R$ independent statistics. Thus, we assume that $\tau_{1r}^{h} = 0$, $\forall \, r$. Also, we assume that $\tau_{1r}^{w} = \tau_{1}^{w}$ for all regions, implying that the frictions in occupation 1 are equal across regions. Also, we fix the TFP of the last region to a constant value, denoted as A_R.

We define the following objective function to our numerical routine:

$$\mathcal{M} = \sum_{i=1,r=1}^{N,R} \left(\frac{W_{ir}^{M} - W_{ir}^{D}}{W_{ir}^{D}} \right)^2 + \sum_{i=1,r=1}^{N-1,R} \left(\frac{p_{ir}^{M} - p_{ir}^{D}}{p_{ir}^{D}} \right)^2 \tag{3.20}$$

The superscripts M and D in equation (3.20) represent the model and target statistics, respectively.[14] We utilize the Nelder-Mead algorithm to minimize equation (3.20), resulting in $\mathcal{M} = 0.00092$, which is considered to be a small number, as we have a total of 378 different targets.

Figure 3.1(a) displays the average hourly wage from the empirical data (vertical axis) and the estimated average hourly wage from the model (horizontal axis). Figure 3.1(b) presents the empirical data (vertical axis) and model-estimated data (horizontal axis) for the share of workers in each occupation and region. The model fits the empirical

[13] Appendix B.1 brings the average hourly wage and the share of workers by occupation and region.
[14] We apply the logarithm in equation (3.20) to improve the algorithm's numerical stability.

data well, as indicated by the points being close to the 45° line. Appendix B.2 brings the calibrated values of τ_{ir}^w, τ_{ir}^h, and A_r.

Figure 3.1 – Model adjustment to data - wages and share of workers

3.4 Results

This section presents and discusses the results of the numerical exercises. Firstly, we compare the results of our simulations with a set of stylized facts. Additionally, we perform a series of counterfactual exercises to assess the sensitivity of simulated GDP to changes in the labor market and educational frictions. Furthermore, we calibrate the model using 2003 data and compare it to the previous calibration to analyze the income convergence process across Brazilian states. Finally, we evaluate the robustness of our results.

3.4.1 Comparing Model Results With a Set of Stylized Facts

The calibrated model produces a good fit for GDP per worker, as illustrated in Figure 3.2 (a). Moreover, as expected, Figure 3.2 (b) shows that the model's results indicate a positive correlation between GDP and TFP.

Figure 3.2 – GDP - Model

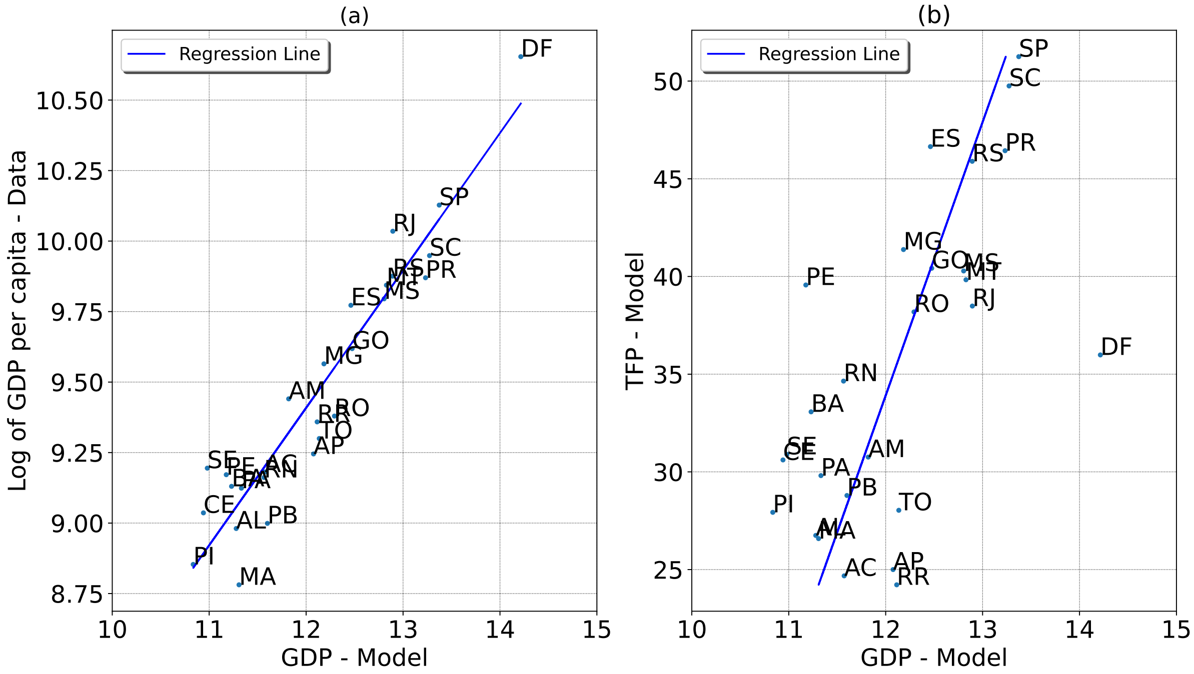


Figure 3.3 presents the model's results and data on teachers' wages relative to other occupations.[15] The model's results also display a good fit for relative wages, and as shown in Figure 3.3, on average, teachers have a higher relative wage in low and middle-income states[16] than in high-income states.[17]

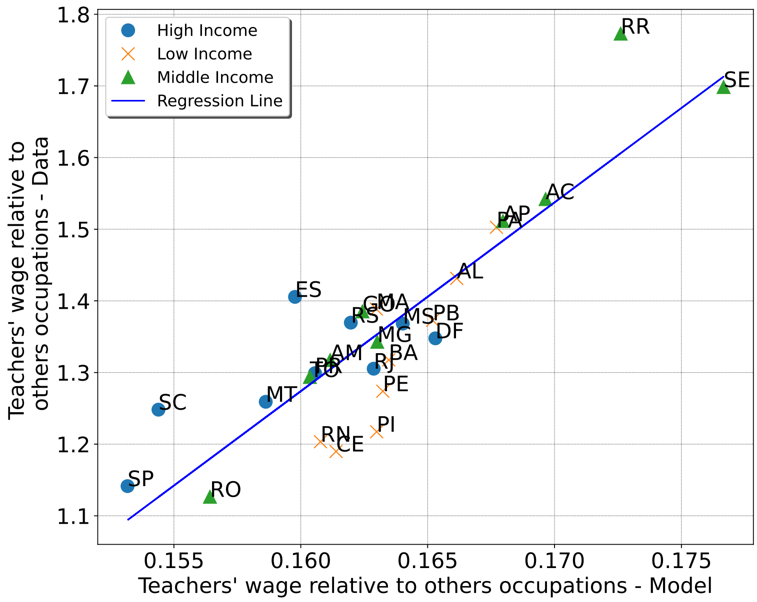
As argued by Barros and Delalilbera (2018), one possible reason for the negative relationship between teachers' relative wages and GDP per capita is that the teaching profession is labor-intensive and less affected by technological and structural changes compared to other occupations. Therefore, in states with more advanced technologies, the relative teachers' wage is lower than in less developed states.

[15] In Brazil, the Law N 11.738 of 2008 regulates the national minimum wage for public teaching professionals in basic education. However, Table B.1 in Appendix B.1 shows that there is wage dispersion among teachers across regions.

[16] We rank the 27 Brazilian states using 2015 GDP *per capita* data. The first nine states are considered high-income, the middle nine are middle-income, and the last nine are low-income.

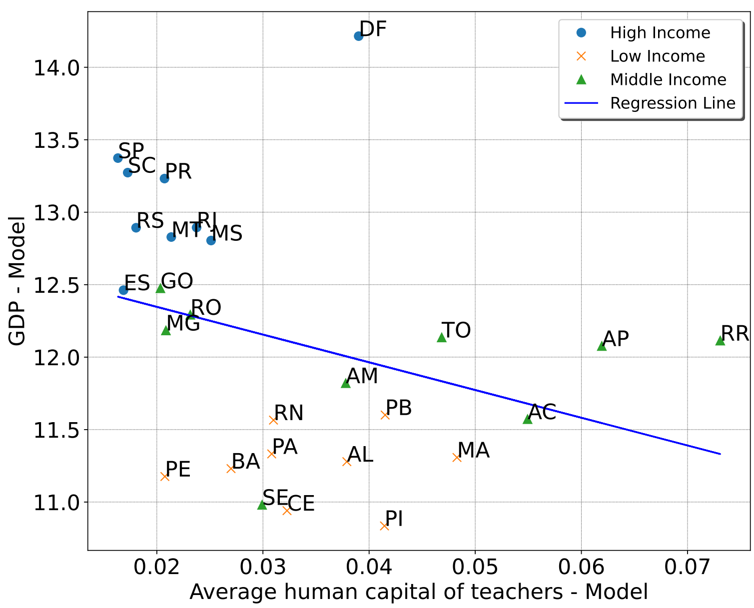
[17] To further investigate the relationship between teachers' relative wages and GDP per capita, we conduct a panel regression analysis with the results presented in Appendix B.6, which provides a more rigorous analysis than our earlier findings. The results of the econometric estimations support our earlier findings and provide additional evidence of the negative relationship between teachers' relative wages and GDP per capita.

Figure 3.3 – Teachers' relative wages



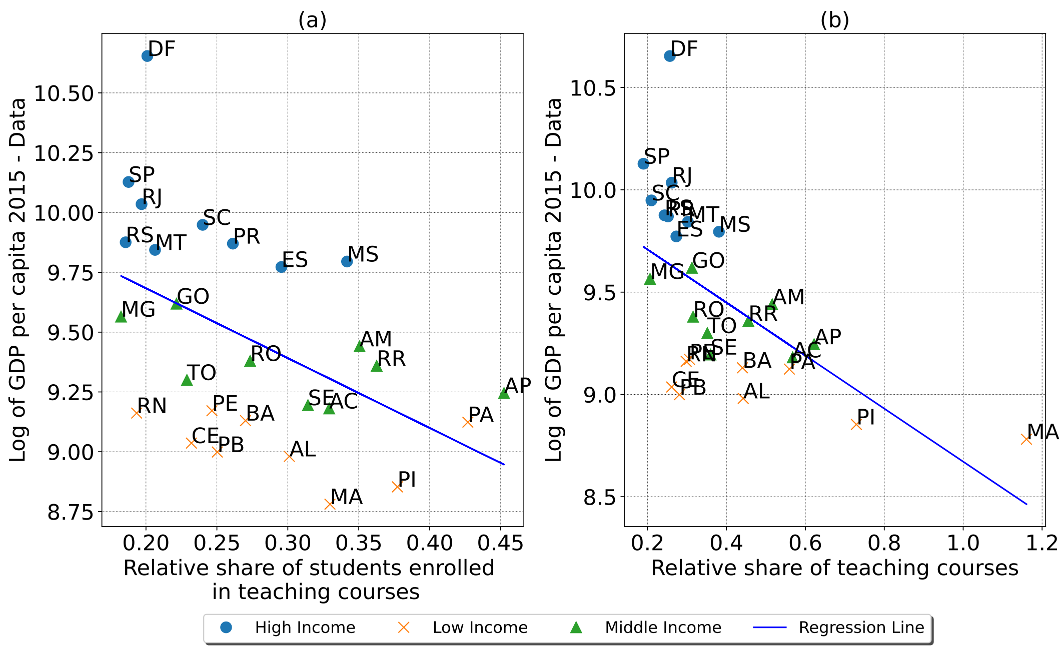
In low-income states, the teaching profession may be more accessible to individuals due to lower labor and educational market barriers compared to richer states. As a result, a higher share of talented people may choose the teaching profession in these states compared to high-income ones, as illustrated in Figure 3.4. Therefore, providing more incentives for talented individuals to become teachers in high-income states may lead to even higher incomes in these regions.

Figure 3.4 – GDP per worker and teachers' human capital



The results obtained are consistent with the available data. Figure 3.5 (a) illustrates that, on average, more students are enrolled in teaching courses in the poorest states than in the wealthiest ones, which can be explained by the fact that the poorest states tend to have a greater number of institutions offering teaching courses, as depicted in Figure 3.5 (b).

Figure 3.5 – Share of students in teaching courses, and share of teaching courses offered



Note: The data used to create this figure was obtained from the Higher Education Census of 2015, which was provided by the National Institute of Educational Studies and Research Anísio Teixeira (INEP).

Additional data findings support the calibration of our model. For instance, in the model, agriculture has the highest average frictions in the educational market, which is consistent with the fact that around 65% of workers in this occupation lived in rural areas in 2015 (PNAD), where access to education is often more challenging.[18] In addition, research has shown that the quality of education in rural schools is generally lower than that in urban areas.[19] On the other hand, at least 92% of workers in other occupations reside in urban areas.

[18] See Appendix B.2 for more details.
[19] See, for example, Williams (2005) and Zhang (2006).

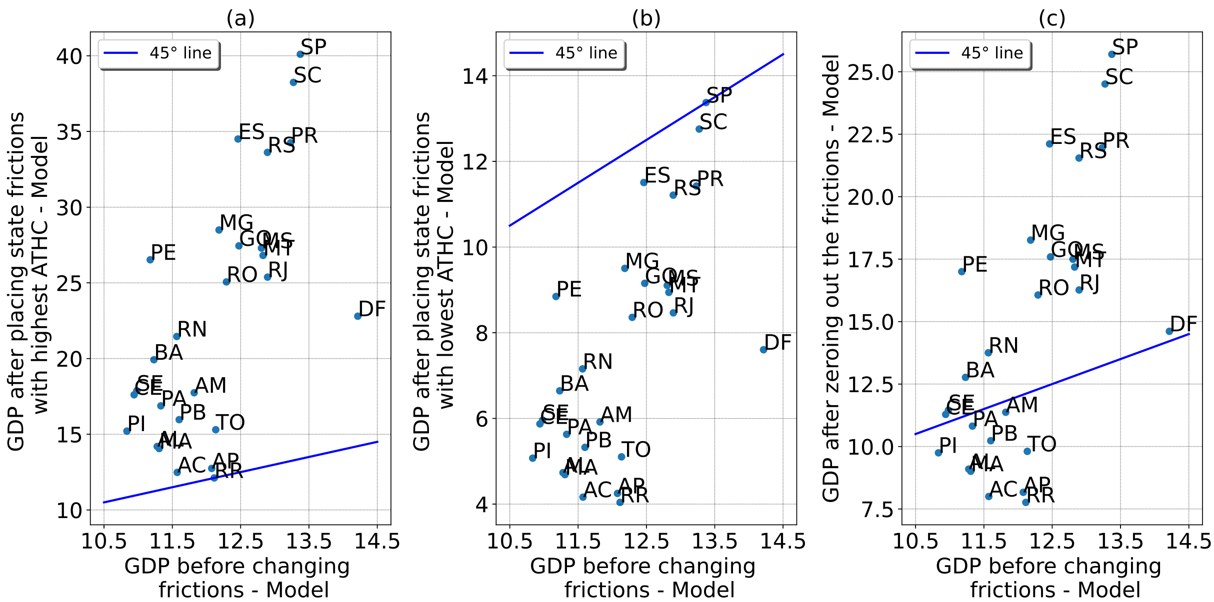
3.4.2 Frictions and GDP

To investigate the economy's sensitivity to frictions, we conduct counterfactual exercises. In Figure 3.6 (a), we assume that all states have the same frictions (τ^w and τ^h) as the one with the highest Average Teachers Human Capital (ATHC), which is Roraima (RR). In this case, our results show that all states would have a significantly higher GDP, with the Brazilian GDP increasing by 87.85%. Moreover, the relative wage of teachers in all states would be equal to the level observed in Roraima.

Conversely, if all states had the same frictions as São Paulo (SP), the state with the lowest ATHC, the GDP of all states would decrease (Figure 3.6 (b)), with the Brazilian GDP declining by 59.62%. Finally, in 3.6 (c), we explore a counterfactual scenario where all frictions are eliminated, resulting in a 16.94% growth in the Brazilian output.

The above counterfactual exercises illustrate the significant impact that frictions have on the economy. However, these exercises involve changing the entire structure of economic incentives, which is a complex matter of public policy. While the results make sense, they cannot be easily implemented.

Figure 3.6 – GDP before and after placing state barriers with the highest and lowest ATHC in all states



Based on this exercise, we can infer that labor misallocation is a significant issue across Brazilian states. When the barriers to entry in the teaching profession are altered, the relative wage for teachers changes, which leads to a reallocation of talent across different occupations. Since becoming a teacher has an externality, meaning that it impacts society as a whole, a modification in frictions that encourages more talented individuals to choose this occupation significantly impact regional GDP.

In the next exercise, we examine how market frictions across all occupations affect GDP *per capita*:

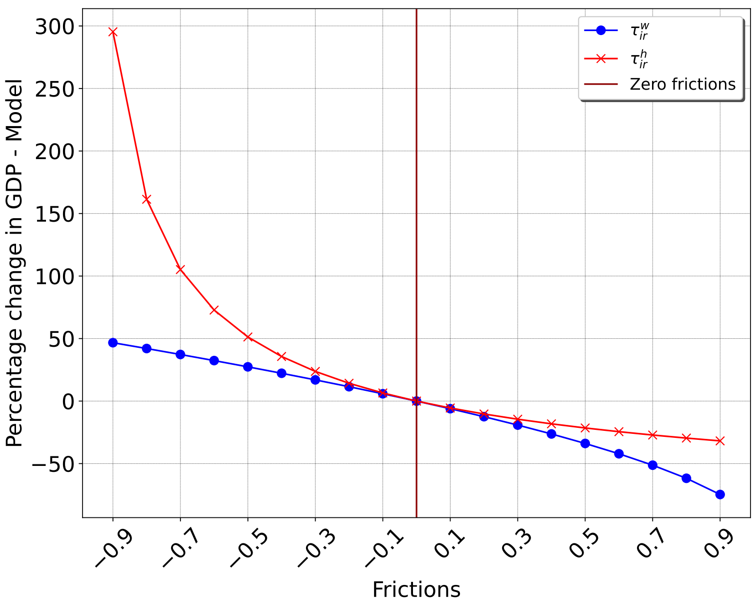
1. We calculate the GDP *per capita* assuming no frictions in both labor and educational markets.

2. We set the educational market frictions to zero and vary the labor market friction from -0.9 to 0.9.

3. Similarly, we conduct an exercise where labor market frictions are set to zero, and we analyze the impact of educational goods market frictions.

Frictions in the educational market act as a "price", enabling consumers to adjust their demand for educational goods. On the other hand, due to the inelastic labor supply, frictions in the labor market only affect the net wages. Therefore, alterations in educational frictions tend to exert a more substantial influence on GDP. Figure 3.7 shows the results.

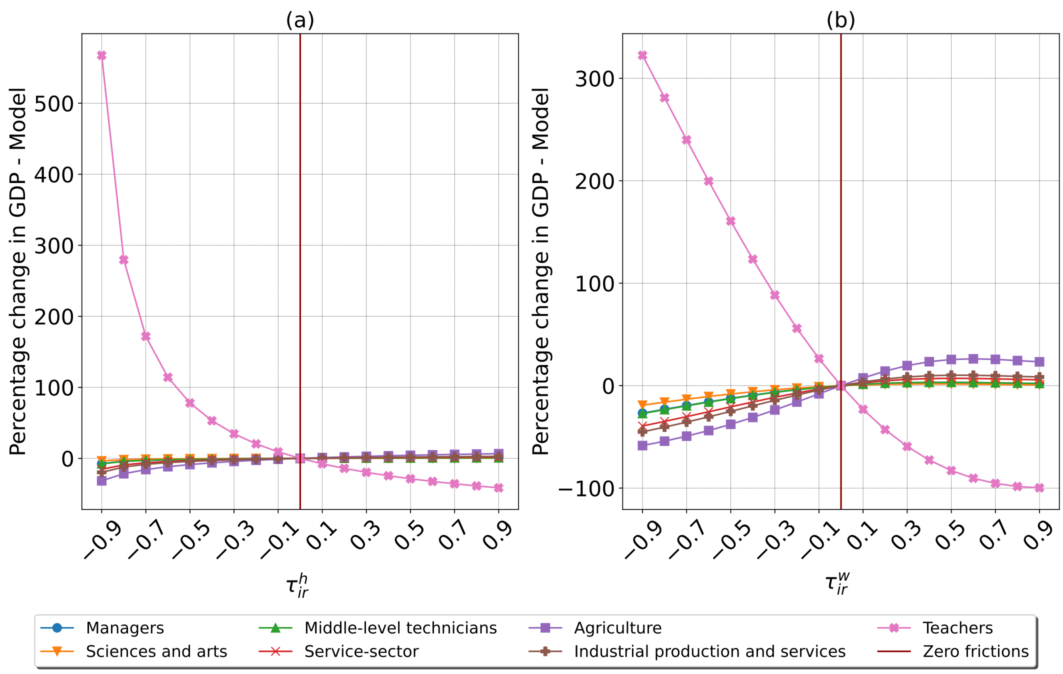
Figure 3.7 – Increases in the frictions of all occupations and the percentage effects on GDP - Model



3.4.3 Teacher's Human Capital

This section examines the impact of changing frictions in each occupation while keeping the frictions in the other occupations at zero. Figure 3.8 reveals that changes in frictions in the teacher's occupation, particularly in the educational goods market, have a more significant effect on GDP than changes in other occupations' frictions. Hence, public policies should incentivize more qualified people to become teachers to promote GDP growth. It should be noted that reducing frictions in other occupations could adversely affect economic performance by reducing the incentives for individuals to become teachers.

Figure 3.8 – Increases in the frictions of each occupation and the percentage effects on GDP

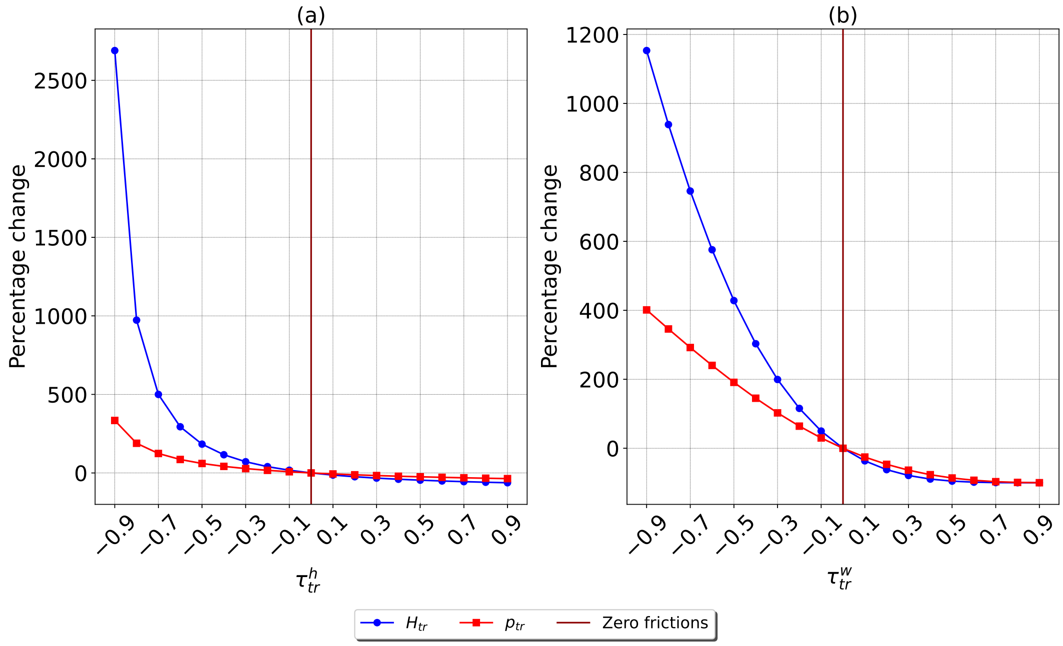


In Figure 3.9, we shift the focus from GDP sensitivity to the impact of frictions on teachers' human capital and the proportion of teachers in the workforce.

The teaching profession becomes more attractive with lower barriers, and as a result, more individuals choose this career path (extensive margin). However, the decrease in barriers may also lead to individuals with lower idiosyncratic skills choosing to become teachers, resulting in a lower average quality of teachers (intensive margin).

Although there is a trade-off between the quality and quantity of teachers in our model, a lower τ^h results in a lower "price" of educational goods (see equation (3.9)). As a result, all workers who choose to become teachers invest more in human capital, compensating for the potential decrease in quality due to the increase in quantity (extensive margin). Therefore, the net effect of reducing barriers is an increase in the average quality of teachers (intensive margin). It is important to note that all these effects are amplified due to the positive externality of teachers on the entire workforce.

Figure 3.9 – Increases in frictions and percentual effects on H_{tr} and p_{tr}



Note: H_{tr} = Human capital of teachers, p_{tr} = proportion of workers in teacher occupation.

3.4.4 Income Convergence

According to the research conducted by Barro and Martin (1992), absolute income convergence happens when economies with lower income grow faster than those with higher income per capita, leading to a decrease in the income gap between poor and wealthy regions over time. To test whether income convergence occurs across the Brazilian states, we utilize data from a model calibrated for 2015 and 2003. To achieve this, we estimate the following equation using Ordinary Least Squares (OLS):

$$\frac{1}{T}\log\left(\frac{Y_{r,2015}}{Y_{r,2003}}\right) = a + b\log(Y_{r,2003}) + \epsilon_r \quad (3.21)$$

Here, $Y_{r,2015}$ and $Y_{r,2003}$ represent the GDP of region r in the years 2015 and 2003, respectively. The model is estimated over T years, with a and b being constants and ϵ_r representing the error term. A negative value of b provides support for the convergence hypothesis.

The findings in Table 3.3 support the hypothesis of absolute income convergence among the Brazilian states since the estimated b is negative and statistically significant. In addition, we have calculated the speed of convergence of this economy, which is $\beta_s = 4.01\%$.[20] The half-life concept can be used to interpret this result, which represents the time required to reduce the income gap by half. The half-life is calculated as $HL = \log(2)/\beta_s$, and we find that it equals 17.3 years.

Table 3.3 – Absolute income convergence across Brazilian states from 2003 to 2015

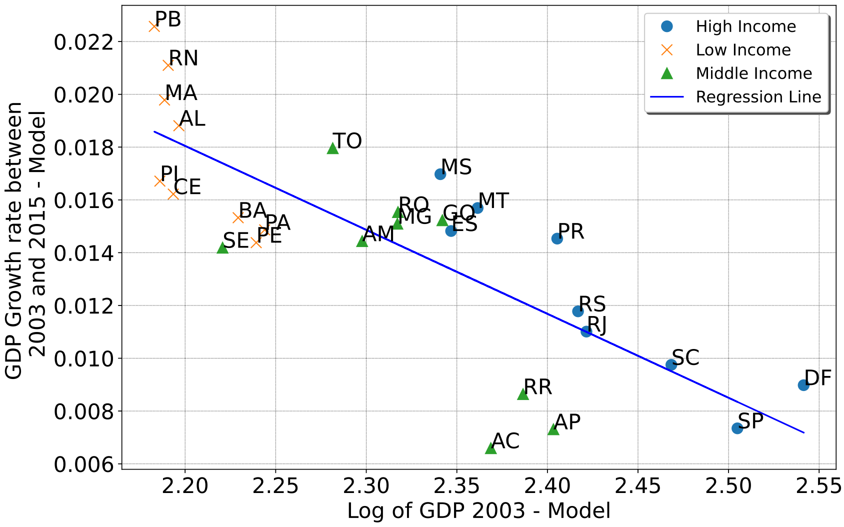
	$\frac{1}{T}\log\left(\frac{Y_{r,2015}}{Y_{r,2003}}\right)$
a	0.0880***
	(0.0114)
b	-0.0318***
	(0.0049)
R-squared	0.6284
R-squared Adj.	0.6136

Source: Search results.
Notes: Standard errors in parentheses. Single (*), double (**) and triple (***) asterisk denote statistical significance at 10%, 5% and 1%, respectively.

The occurrence of absolute income convergence among Brazilian states from 2003 to 2015 is further evidenced by Figure 3.10. This plot clearly shows that low-income states, such as Paraíba (PB), Rio Grande do Norte (RN), Maranhão (MA), Alagoas (AL), Piauí (PI), and Ceará (CE), experienced relatively fast income growth in this period. Conversely, high-income states, including the Federal District (DF), São Paulo (SP), Santa Catarina (SC), Rio de Janeiro (RJ), and Rio Grande do Sul (RS), exhibited slower growth rates.

[20] The formula for the speed of convergence is given by: $\beta_s = -\frac{\log(Tb+1)}{T}$.

Figure 3.10 – Growth rate from 2003 to 2015 and Log of GDP 2003



The occurrence of absolute income convergence among Brazilian states from 2003 to 2015 can be explained by multiple factors, including a reduction in educational market frictions and an increase in Total Factor Productivity (TFP).[21] Our analysis reveals that educational frictions have decreased more sharply in the poorest states and Rio de Janeiro. Additionally, there has been an average reduction in frictions for occupations in the teaching occupation. However, the most substantial reduction in friction occurred in the agriculture sector, likely due to the increase in the average years of education of Brazilian agricultural workers.

Our analysis also indicates a slight increase in labor market barriers from 2003 to 2015, on average. However, as depicted in Figure 3.7, the impact of increases in labor market barriers on GDP is relatively small compared to reductions in educational market frictions.

3.5 Robustness check

We present the results of our robustness analysis in Table 3.4. To conduct this analysis, we performed a counterfactual exercise similar to that presented in Section 3.4.2,

[21] Appendix B.2 provides the calibrated frictions and TFP for 2003.

where we set the market frictions (τ^w and τ^h) to match those of the states with the highest and lowest Average Teachers' Human Capital (ATHC).

In our counterfactual exercise, when we change the educational goods elasticity in the human capital function η using the frictions of the state with the highest ATHC (Roraima), GDP increases substantially from 2.71% ($\eta = 0.05$) to 87.85% with our baseline $\eta = 0.129$, and up to 162.36% when $\eta = 0.25$. The results are analogous when we use the frictions of the state with the lowest ATHC (São Paulo). Therefore, we can conclude that changes in η substantially impact GDP, regardless of the specific state used in the counterfactual exercise. Among all parameters tested in our robustness analysis, we find that GDP is most sensitive to changes in η and φ.

In the following two lines of Table 3.4, we analyze the sensitivity of skill dispersion, represented by the parameter θ. In the second column, we observe that when skill dispersion is given by $\theta = 2$, GDP is 57.95% higher and 90.41% greater when $\theta = 3$. The third column shows that changes in θ have a more significant impact on GDP in an economy with higher frictions. Moreover, the parameter β also positively affects GDP.

One critical parameter in the human capital function is the one measuring the trade-off between the quantity and quality of teachers. By increasing α, we place more weight on the number of teachers in relation to their quality (average human capital of teachers).[22] When we set $\alpha = 0.2$, GDP increases by 107.55%, and it is 57.87% higher when $\alpha = 0.6$.

[22] Recall that $T_r = p_{tr}^{\alpha} H_{tr}^{(1-\alpha)}$, where H_{tr} is the average human capital of teachers and p_{tr} is the proportion of teachers in region r.

Table 3.4 – Robustness check for constant parameters

Parameter	GDP variation (Largest ATHC)	GDP variation (Lowest ATHC)	GDP variation (Zero Frictions)
$\eta = 0.05$	2.71%	-14.07%	9.31%
$\eta = 0.25$	162.36%	-108.50%	20.22%
$\theta = 2.0$	57.95%	-48.50%	21.19%
$\theta = 3.0$	90.41%	-60.59%	16.68%
$\beta = 0.1$	80.46%	-52.38%	-0.29%
$\beta = 0.3$	88.52%	-61.37%	18.35%
$\alpha = 0.2$	107.55%	-73.20%	18.29%
$\alpha = 0.6$	57.87%	-38.79%	14.41%
$\varphi = 0.1$	8.44%	-16.06%	20.20%
$\varphi = 0.6$	162.13%	-99.39%	13.19%
Benchmark	87.85%	-59.62%	16.94%

Source: Search results.

Notes: ATHC is Average teacher human capital. The baseline values are $\eta = 0.129$, $\beta = 0.231$, $\theta = 2.52$, $\varphi = 0.48$ and $\alpha = 0.31$.

Finally, we examine the sensitivity of our results to the teacher's contribution to human capital formation, denoted by φ. As shown in Table 3.4, an increase in this parameter has a significant positive influence on GDP. Therefore, teachers play a critical role in driving economic performance in our economy.

3.6 Final Remarks

In this paper, we develop a Roy model to investigate the influence of market frictions on labor and educational markets in Brazil. Additionally, we incorporate a function where teachers play a crucial role in the human capital formation of the entire workforce. After calibrating the model to Brazilian data, we find a positive correlation between barriers related to the teacher's occupation and GDP across Brazilian states. We also show that increasing the attractiveness of the teaching occupation results in higher GDP. When more individuals with higher idiosyncratic abilities pursue teaching careers, they directly affect the workforce's productivity. These findings highlight the importance of addressing market frictions in the education and labor sectors and underscore the critical role of teachers in promoting economic growth.

Furthermore, our calibrated model for 2015 suggests that the main driver of absolute income convergence was the reduction of frictions related to the teaching profession. This reduction led to an increase in the average human capital and productivity of the entire economy. Therefore, policymakers should focus on increasing incentives for individuals to pursue teaching as a career, particularly for those with higher idiosyncratic abilities, to attract more talented people.

Due to the practical challenges involved in selecting high-quality teachers, it is important to interpret our findings with caution. Identifying individuals with high ability in this occupation is a challenging task. For instance, Rivkin, Hanushek and Kain (2005) estimate teacher quality using a detailed micro dataset and find that factors such as teachers' experience and education explain very little of teacher quality. Further research is needed to determine the most effective strategies for enhancing the attractiveness of the teaching profession. For instance, policymakers could consider implementing strategies to enhance the attractiveness of the teaching profession, such as creating career paths for teachers based on their performance and offering salaries comparable to those of similarly qualified professionals in other fields. Additionally, providing a work environment that fosters collaboration among teachers, investing in their training, and offering a good retirement plan could also be effective incentives. Further research is necessary to better understand the factors that drive individuals to choose a career in teaching and how to improve the quality of the teacher workforce.

There is potential for further research that accounts for differences in risk levels across occupational options and incorporates heterogeneity in workers' wealth. Such an extension could shed light on how wealth, risk, and the marginal utility of consumption influence occupational choices, and it is a promising direction for future research. Furthermore, investigating the misallocation of teachers across different educational stages could offer further insight into the efficiency of the education system and provide opportunities for targeted policy interventions. For instance, analyzing the allocation of teachers between primary, secondary, and tertiary education, and evaluating how this allocation affects human capital accumulation could be a fruitful area of research. Therefore, future studies could explore these extensions to expand upon our findings and provide a deeper understanding of the dynamics of occupational choices and teacher allocation, which would help inform policy decisions to improve the allocation of human capital and promote economic growth.

4 Economic Development and Spillover Effects of Intermediate Goods and Services

Abstract

In this paper we study the spillover effects of intermediate goods and services on income. We show that the share of intermediate inputs decreases in industry and agriculture as the countries' level of development increases, and the opposite occurs in modern and traditional services. We also show that there is a structural change underway in economies that is causing industry to lose share in intermediate goods while the traditional and especially modern services sector gains share. We develop a general equilibrium model to quantitatively evaluate the effects of productivity changes and changes in the productive structure on the income gap in developed and developing countries. We then show that closing productivity gaps in industry has a greater average impact on GDP per worker and aggregate productivity, when compared to other sectors. Furthermore, we show that in countries with highly efficient agricultural and/or industrial sectors, a structural change that makes services sector gain share in the economy, without the necessary increase in productivity, would further increase the GDP gap per worker.

Keywords: Intermediate Goods; Production Networks; Productivity.

4.1 Introduction

Sectoral total factor productivity (TFP) and interdependence between sectors through the use of intermediate goods are two of the factors identified as key to understanding differences in countries' levels of development (JONES, 2011b; HERRENDORF; VALENTINYI, 2012; HERRENDORF; ROGERSON; VALENTINYI, 2014; INKLAAR; ALBARRÁN; WOLTJER, 2019; FADINGER; GHIGLINO; TETERYATNIKOVA, 2022). The interdependence between sectors through the use of intermediate inputs means that the effect of a productivity change in a specific sector spills over into other sectors of the economy.[1] As in Jones (2011b), if a sector experiences an improvement in productive efficiency, the other sectors that use intermediate goods from that sector will benefit. In this paper, we address both factors, specifically, we study how productivity changes in a specific sector spill over to other sectors of the economy through intermediate goods and contribute to reducing the income gap relative to the United States.[2] In this sense, our paper is related to studies that combine structural transformation and insights into production network theory (JONES, 2011a; JONES, 2011b; HERRENDORF; ROGERSON; VALENTINYI, 2014; CARVALHO, 2014; BARROT; SAUVAGNAT, 2016; ATALAY, 2017; FERREIRA; DELALIBERA; VELOSO, 2021).

We explore the World Input-Output Database (WIOD) dataset from 2014 that covers 43 countries and 56 sectors and we categorized this sectors into four major sectors: agriculture, industry, modern and traditional services. We find that there are gaps in GDP per worker, at the sectoral and aggregate level, between the sample countries and the United States. These gaps are largest in agriculture and smallest in the traditional services sector. Furthermore, we show that the share of intermediate inputs decreases in industry and agriculture as the countries' level of development increases, and the opposite occurs in modern and traditional services. We also show that there is a structural change underway in economies that is causing industry to lose share in intermediate goods while the traditional and especially modern services sector gains share.

[1] In this paper we use productivity and total factor productivity as synonyms.
[2] Income gaps are calculated as the ratio between GDP per worker in the United States and other countries.

Then, we developed a general equilibrium model to quantitatively evaluate the effects of productivity changes and changes in the productive structure on income gaps in countries. In our baseline calibration, we show that the productivity of modern services is on average higher than that of other sectors of the economy. Also, we conducted two counterfactual exercises; in the first, we insert the sectoral productivity of the United States, one at a time, in the other countries; and in the second, we insert the elasticity of intermediate goods. Our findings show that closing productivity gaps in industry has a greater effect on GDP per worker and aggregate productivity, both at the sectoral and aggregate levels, compared to other sectors. Furthermore, we show that inserting the elasticity of United States intermediate goods in other countries makes the sectoral share of intermediate goods similar to that of the United States, on average; and consequently these economies become more service-oriented. However, many of these economies, for example China's, are more efficient in industry and this structural change that forces them to produce more in the services sector, where they are not as efficient, further increases the gap in GDP per worker.

Some studies have examined the contribution of structural transformation to increased productivity. Bah and Brada (2009) examined nine transition economies and found that the productivity of the manufacturing sector surpassed that of services in all countries, suggesting that reallocating labor to the service sector could reduce aggregate productivity. Duarte and Restuccia (2010) studied 29 countries from 1956 to 2004, concluding that during structural transformation, shifting labor from agriculture to manufacturing increases aggregate productivity, while a shift to services decreases it. Ferreira and Silva (2015) focused on nine Latin American countries, noting that despite low productivity and growth in the traditional services sector, it has absorbed a significant amount of labor, hindering productivity expansion in these countries. We find that, on average, the productivity of modern services is higher than in other sectors. This implies that moving workers from less productive sectors, for example agriculture, to this sector could result in greater gains in GDP per worker and aggregate productivity.

Herrendorf, Rogerson and Valentinyi (2022) suggests that moving workers to manufacturing is not the best solution for the economic development of countries; however, improving labor productivity in manufacturing can contribute to aggregate productivity growth in poor countries. We advance on this topic by showing that in the case of industry, closing the average sectoral productivity gap of 30.58% led to an average reduction of 20.96% in the productivity gap at the aggregate level. This effect is proportionally greater than in other sectors.

Other studies highlight the role of sectoral linkages through input-output and their relationship with aggregate output, and this affects the GDP per worker on aggregate level. Several of them suggest that idiosyncratic microeconomic shocks that propagate through sectoral production networks within a specific economy can help explain the origins of fluctuations in aggregate output (BARROT; SAUVAGNAT, 2016; ATALAY, 2017; BAQAEE, 2018; BOEHM; FLAAEN; PANDALAI-NAYAR, 2019; FROHM; GUNNELLA, 2021). Our findings corroborate this literature. We show that closing the productivity gap in a specific sector causes an increase in the production of intermediate goods in that sector. Consequently, this results in a reduction in prices, which in turn increases the demand for intermediate production factors in this sector. We also calculate the Bonacich-Katz centrality index, which measures the importance of a sector as a supplier to the economy and provide evidence that, on average, the industry plays a central role in the productive structure of countries, that is, it is the sector with greater capacity to boost demand for intermediate goods in other sectors, especially in less developed countries.

Rodrik (2016) documents that there is a tendency of premature deindustrialization in low and middle-income countries, that is, low and middle-income countries are becoming service economies without having gone through adequate industrialization experience. According to him, premature deindustrialization has negative effects on economic growth, mainly because industry is a technologically dynamic sector, absorbs a large amount of unskilled labor, and is a tradable sector, that is, it does not have many restrictions on demand in domestic markets populated by low-income consumers. In our counterfactual exercise, we show that closing the productivity gap in industry has a greater average impact on the GDP gap per worker, both at the sectoral and aggregate levels, when compared to other sectors. The 30.58% reduction in the sectoral productivity gap, in industry, led to a 75.72% and 47.39% reduction in the GDP per worker gap at the sectoral and aggregate levels, on average, respectively.

We also analyzed what would happen to the economies of the sample countries if their production structures converged with those of the United States. Specifically, what we do is predict what would happen to economies if industry actually lost share and they became more service-oriented. We show that this change only benefits the modern services sector and that in countries with highly efficient agricultural and/or industrial sectors, this structural change leads to a reduction in the amount of labor and the production of intermediate goods. Therefore, these sectors start to produce less, which, in turn, results in even greater income gaps.

Furthermore, our study is also related to the literature that addresses the importance of the service sector in economic development. Eichengreen and Gupta (2013) emphasizes that the share of modern services in GDP has been increasing since the 1970s, and this is related to technological advances that have allowed greater complementarity between traditional and modern services. We show that changes in productivity in modern services have a greater average impact on GDP per worker compared to traditional services. However, variations in the productivity of traditional services have a greater average impact on aggregate productivity compared to modern services. This effect is related to the fact that traditional services have a large share of added value and labor. We also demonstrate that the traditional services sector is more central that modern services and has a greater capacity to stimulate demand from other sectors.

In addition to this introduction, this paper is organized as follows. Section 4.2 presents the dataset that we used in our analysis and some stylized facts on value added per worker gaps between countries, and the trend of the sectoral share of intermediate goods in economies. Section 4.3 presents our general equilibrium model. Section 4.4 explains how this model is calibrated for 39 countries. The calibration results, comparison of the model with some empirical facts, and the two counterfactual exercises are presented in

Section 4.5. Finally, Section 4.6 brings our concluding remarks.

4.2 Datasets and Stylized Facts

In this section, we present the dataset used in the paper and some stylized facts observed from this dataset. We begin the section by describing the World Input-Output Database (WIOD) and the Socio Economic Accounts (SEA). We then discuss the gaps in GDP per worker at the sectoral and aggregate levels. And finally, we discuss the share of intermediate goods in economies and the trends in sectoral production.

4.2.1 Dataset

In this paper, we utilize data sourced from the World Input-Output Database (WIOD). This dataset offers a time series of input-output matrices (IO) that spans 2000 to 2014, and covers 43 countries and 56 sectors.[3] Additionally, WIOD provides data pertaining to input quantity, prices, and volumes, including information on value added, capital stock, workers, and hours worked. These datasets are available within the Socio-Economic Accounts (SEA). For a more comprehensive introduction to this database, see Timmer et al. (2015).

Our analysis focuses on data from 2014.[4] We exclude countries with populations of fewer than one million inhabitants, namely Luxembourg and Malta, from our sample. Additionally, due to a lack of available data, we excluded Taiwan and Croatia, resulting in a sample size of 39 countries. We provide the names and acronyms of each country in Table C.1 in Appendix C.1. Furthermore, to facilitate cross-country comparisons of monetary values, we employ Purchasing Power Parity (PPP) data provided by the Organization for Economic Cooperation and Development (OECD); this indicator is measured in terms of

[3] It is important to emphasize that we utilize the updated 2016 version of WIOD, as outlined by Timmer et al. (2016). This latest version provides an annual time series of World Input-Output Tables (WIOTs) spanning from 2000 to 2014 (compared to 1995-2011 in the 2013 version) and covers 43 countries (compared to 40 in the 2013 version).

[4] We highlight that in Subsection 4.2.2.2 where we analyze the trend in sectoral production, we use data from 2000 to 2014.

national currency per US dollar.[5]

Based on International Standard Industrial Classification of All Economic Activities (ISIC 4) we have classified the 56 sectors identified in the Socio-Economic Accounts (SEA) into three broad sectors: agriculture, industry, and services.[6] The agriculture sector encompasses activities such as animal production, hunting, fishing, forestry, and logging. The industry sector covers manufacturing, electricity, gas, water, mining and quarrying, waste treatment and disposal, and construction.

Regarding the services sector, we follow Ferreira and Silva (2015) and divide it into two: modern services and traditional services. We consider modern services to be the sectors within services that have the highest added value per worker. Modern services include financial services, real estate activities, insurance, scientific research, management consultancy, among others. In contrast, traditional services include educational services, healthcare, postal and courier activities, transportation, public administration and defense, and other related activities.[7] On average, the value added per worker of modern services is 2.4 times higher than in traditional services.

We adopted this approach because the services sector is quite heterogeneous, that is, various activities within this sector involve workers with varying skill levels, distinct levels of productivity, and varying degrees of economic significance. For instance, employees in the educational services sector typically possess different skills and exhibit different levels of productivity compared to those in the tourism sector. Our sector classification can be seen in Table C.3 in Appendix C.4.

4.2.2 Stylized Facts

4.2.2.1 GDP per worker Gaps

According to Herrendorf, Rogerson and Valentinyi (2022), one of the channels for driving economic growth is to reallocate labor to sectors where productivity gaps are

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[5] This indicator can be accessed on the OECD website: https://data.oecd.org.

[6] ISIC can be view in United Nations website: https://unstats.un.org.

[7] A similar approach was employed by Rogerson (2008), Eichengreen and Gupta (2011) and Eichengreen and Gupta (2013).

smaller, at the aggregate and sectoral level. In this context, agriculture, typically the least productive sector, plays a crucial role in explaining cross country income gaps, since less developed countries allocate a significant part of the workforce in this sector. In India, Indonesia, and China, the labor share in agriculture is 45%, 31%, and 24%, respectively. In this sense, the income gaps between the least developed and the most developed countries would tend to decrease if the labor force was reallocated from agriculture to the more productive sectors of the economy.

In this section, we document the gaps in GDP per worker, both at the sectoral and aggregate levels, between the countries in the sample and the United States.[8] This measure is defined as the ratio of GDP per worker in the United States to that of the other countries. We use the United States as a reference because this country is one of the countries that comes closest to the technological frontier (HERRENDORF; ROGERSON; VALENTINYI, 2022).

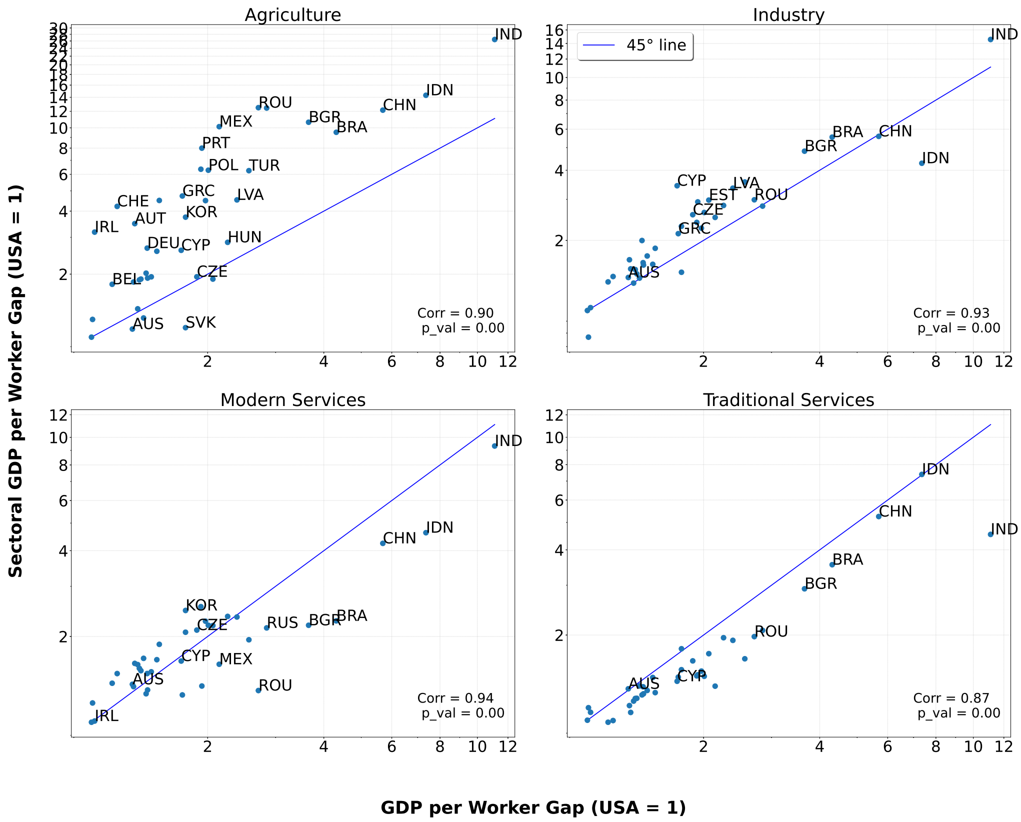
Figure 4.1 presents the results, with points below (above) the 45-degree line indicating countries where the gap in aggregate GDP is greater (lower) than the gap in sectoral GDP. We highlight two facts. Firstly, the GDP gap in agriculture is larger than in other sectors in most countries. The average gap in agriculture is 5.2, indicating that the value added per worker in the United States is on average 5.2 times higher than in the other countries. In developing countries, the gaps are even greater; for example, India, Indonesia, and China have gaps of 26.46, 14.3, and 12.5, respectively. Furthermore, on average, the gap in agriculture is greater than in the aggregate, which is 2.28. This result is consistent with findings by Restuccia and Rogerson (2008), Herrendorf and Valentinyi (2012), Gollin, Lagakos and Waugh (2014), Herrendorf, Rogerson and Valentinyi (2022). In industry, the gap is smaller than in agriculture, on average 2.66, but it is larger than in the aggregate.

Secondly, the GDP per worker gap in the traditional and modern service sectors are, on average, 1.82 and 2.05, respectively, that is, lower than the GDP per worker gap

[8] Some papers assume that GDP per worker is a measure of labor productivity (RESTUCCIA; ROGERSON, 2008; HERRENDORF; VALENTINYI, 2012; GOLLIN; LAGAKOS; WAUGH, 2014; HERRENDORF; ROGERSON; VALENTINYI, 2022).

at the aggregate level. In this sense, if workers move from agriculture to the service sector, especially traditional services, the gap in value added per worker at an aggregate level would tend to reduce more than if these workers moved to industry, for example.

Figure 4.1 – GDP per Worker Gap, Aggregated and Sectoral - 2014



Notes: This figure is on logarithmic scale. Points below (above) the 45-degree line indicating countries where the gap in aggregate GDP is greater (lower) than the gap in sectoral GDP.

However, aggregate productivity gains resulting from labor reallocation can be exhausted, as most labor is already allocated to the most productive sectors of the economy. An alternative channel to fill these gaps and achieve economic growth is improvement in productive efficiency. Productivity changes in a sector increase its production and reduce costs, which in turn, through intermediate goods, affect other sectors of the economy. In this context, two important questions emerge. And if instead of reallocating labor there was an increase in productivity in these sectors, which one has the greatest capacity to reduce the income gaps? And in the context in which intermediate inputs create networks between sectors, which one has the greatest capacity to stimulate the production of the others? We address these questions in the following sections.

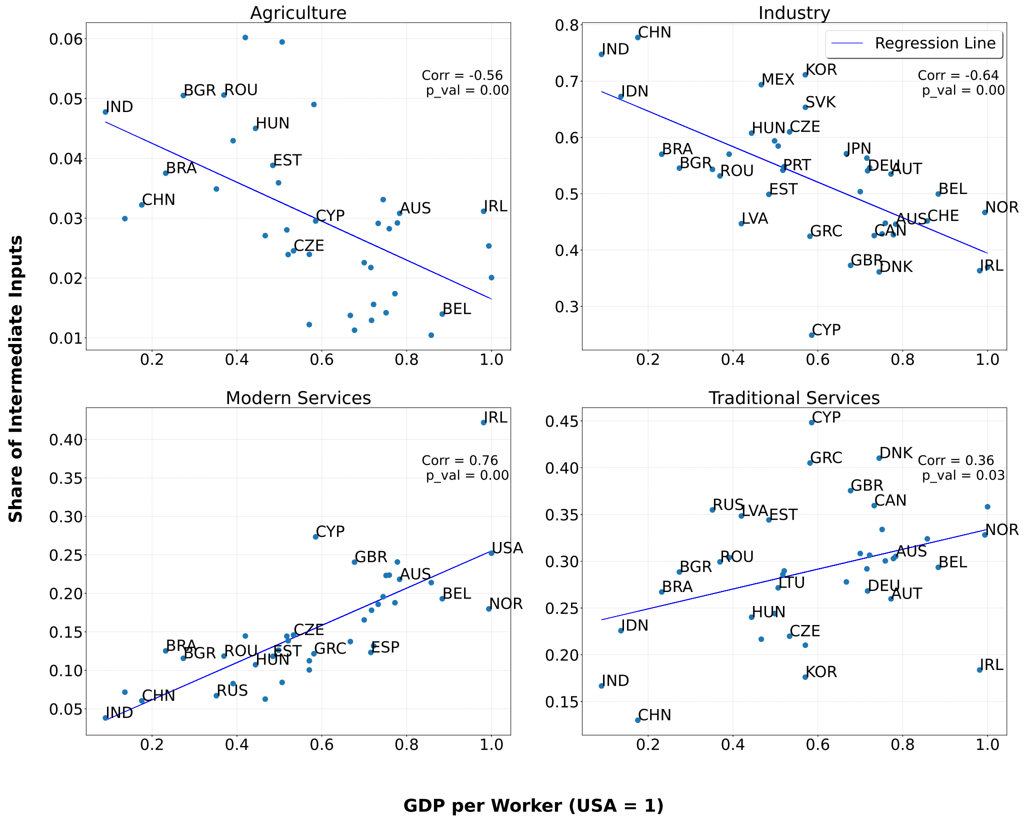
4.2.2.2 Intermediate Inputs

The IO matrix represents the flow of intermediate goods between different sectors. The flow of intermediate goods determines the pattern of trade across sectors and creates networks between then, acting as a shock propagation mechanism, that is, a positive (negative) shock in the productivity of an important sector has a positive (negative) impact on all other sectors (JONES, 2011a; CARVALHO; TAHBAZ-SALEHI, 2019; BOEHM; FLAAEN; PANDALAI-NAYAR, 2019; FADINGER; GHIGLINO; TETERYATNIKOVA, 2022).

In Figure 4.2, we illustrate the cross-country distribution of the share of intermediate inputs on the supply side by sector. It is worth noting that the share of intermediate goods tends to decrease in the agriculture and industry sectors as the level of development increases. Conversely, in the service sector, the share of intermediate goods tends to rise with increasing development levels.[9] This observation is consistent with the literature on structural change, which provides evidence that both value added and the share of employment in the service sector increase as countries develop (HERRENDORF; ROGERSON; VALENTINYI, 2014; HERRENDORF; SCHOELLMAN, 2018; SPOSI, 2019).

[9] The sectoral gross output, value added and labor share exhibits a pattern similar to that depicted in Figure 4.2.

Figure 4.2 – Share of Intermediate Inputs by Sector - 2014



Apparently, the services sector, especially modern services, has greater importance in the productive structure of more developed countries, while agriculture and industry has greater importance in less developed countries. However, industry tends to lose importance as economies specialize in the service sector. Rodrik (2016) documents that there is a tendency to premature deindustrialization in low- and middle-income countries, that is, low- and middle-income countries are becoming service economies.

To verify whether deindustrialization has been faster in recent periods, Rodrik (2016) used an econometric model with panel data in which the dependent variable is the share of labor in manufacturing, and the controls are the effects of demographic and income trends, as well as fixed effects of countries.[10] We follow Rodrik (2016) and estimate a similar econometric specification; however, our objective is to analyze the trend in sectoral share of intermediate inputs. Our specification is the following:

[10] In alternative specifications Rodrik (2016) also uses as dependent variable the share of value added in real values and the share of value added in current values.

$$II_{jt}^{share} = \beta_0 + \beta_1 \ln pop_{jt} + \beta_2(\ln pop_{jt})^2 + \beta_3 \ln y_{jt} + \beta_4(\ln y_{jt})^2 + \sum_j \gamma_j C_j + \sum_T \omega_T D_T + \epsilon_{jt}, \quad (4.1)$$

where II_{jt}^{share} is the share of intermediate inputs of country j in period t, pop is the population, y_{jt} is the GDP per capita, also there are quadratic terms for $\ln pop_{jt}$ and $\ln y_{jt}$, C_j are country fixed effects, D_T are period dummies, and ϵ_{jt} is an error term. Here, we use data from 2000 to 2014 and capture sectoral trends using period dummies for the 2003 – 2005, 2006 – 2008, 2009 – 2011, and 2012 – 2014.

Table 4.1 reports the results of the regression estimated using Equation 4.1 for the four sectors. The key parameters of interest are those for the time fixed effects, D05, D08, D11, and D14. These parameters show the share of intermediate inputs of each period relative to the excluded period 2000 – 2002. Columns 1 and 2 present the estimates for agriculture and industry and indicate that both sectors, especially industry, have been losing share in total intermediate inputs as time progresses. Columns 3 and 4 present the estimates for modern and traditional services and point to a contrary pattern to the first two sectors, that is, as in Rodrik (2016), as time progresses, the share of both sectors in the total of intermediate inputs increases, that is, these economies are becoming service sector-oriented economies.[11]

[11] In Table C.2 in Appendix C.3 we show that the share of sectoral value added presents a similar pattern to the share of sectoral intermediate inputs.

Table 4.1 – Panel Regression Models, Sectoral Share of Intermediate Inputs - 2000:2014

	Dependent Variable: Share of Intermediate Inputs			
	(1) Agriculture	(2) Industry	(3) Modern Services	(4) Traditional Services
Ln GDP per Capita	-0.064^{***}	0.052^{**}	0.079^{***}	-0.067^{***}
Ln GDP per Capita Squared	0.007^{***}	0.0002	-0.014^{***}	0.006^{*}
Ln Population	-0.336^{***}	-0.639^{***}	1.373^{***}	-0.398^{**}
Ln Population Squared	0.011^{***}	0.016^{**}	-0.040^{***}	0.013^{**}
D05	-0.003^{***}	-0.002	0.002	0.003
D08	-0.005^{***}	0.003	0.003	-0.001
D11	-0.003^{***}	-0.017^{***}	0.010^{***}	0.010^{***}
D14	-0.003^{**}	-0.018^{***}	0.010^{***}	0.011^{***}
Country Fixed Effects	✓	✓	✓	✓
Observations	585	585	585	585
R^2	0.562	0.262	0.265	0.114
Adjusted R^2	0.525	0.199	0.203	0.038
F Statistic (df = 8; 538)	86.458^{***}	23.852^{***}	24.287^{***}	8.630^{***}

Notes: Statistical significance is indicated at the $***p < 0.01$, $**p < 0.05$, and $*p < 0.1$ levels. Our dataset comprises data from 2000 to 2014. We use four time dummies variables: D05, D08, D11, and D14 that indicate whether the period goes from 2003 to 2005, 2006 to 2008, 2009 to 2011 and 2012 to 2014, respectively. Note that we exclude dummy that indicates the period goes from 2000 to 2002.

If economies actually converge towards a structure in which the service sector, both modern and traditional, are more important than the others, would this lead to a reduction in the income gap between countries? To answer this question and the others raised in Section 4.2.2.1, we developed a general equilibrium model in which we make explicit the importance of productivity and intermediate goods in the production function. We calibrate the model and conducted a series of counterfactual exercises.

4.3 Theoretical Framework

In this section, we present our theoretical framework, based on Carvalho (2014) and Ferreira, Delalibera and Veloso (2021), to study the effects of sectoral productivity changes and its spillover effects through intermediate goods on the final output of the economies. Our model has four sectors: agriculture, industry, traditional and modern services, and in the production function we make explicit the relationship between them through intermediate goods. In this context, the productivity changes in one sector spills over into the others. First, we describe the production technology and the firm's problem, then the representative consumer preferences. Next, we present the equilibrium conditions and the optimal solution of the model, and finally, we discuss how productivity changes affect the production chain and the final product of the economy.

4.3.1 Firms

In this economy, there is a continuum of homogeneous and competitive firms in each of the N productive sectors. They maximize profits by optimally choosing how much to employ labor and how much to use each of the intermediate goods. The production technology is given by:

$$Q_i = A_i L_i^{\sigma_i} \left(\prod_{j \in N} X_{ij}^{\beta_{ij}} \right)^{1-\sigma_i}, \quad i \in N, \tag{4.2}$$

where Q_i is the gross product of sector i, A_i is the total factor productivity, L_i is the amount of labor employed and X_{ij} is the matrix of intermediate goods where the columns indicate the sector of origin of the goods and services while the rows indicate the sector of destination. Furthermore, σ_i is the elasticity of the good of sector i with respect to labor and β_{ij} is the elasticity of the set of intermediate goods j with respect to the specific intermediate good i. Specifically, a high β_{ij} indicates that sector j produces more intermediate inputs for sector i, while $\beta_{ij} = 0$ indicates that input j is not needed in the production of good i, we also assume that for all j $\sum_{j \in N} \beta_{ij} = 1$.

The firm's problem can be written as:

$$\max_{X_{ij}, L_i} \quad p_i Q_i - w L_i - \sum_{j \in N} p_j X_{ij}, \tag{4.3}$$

$$\text{st:} \quad Q_i = A_i L_i^{\sigma_i} \left(\prod_{j \in N} X_{ij}^{\beta_{ij}} \right)^{1-\sigma_i},$$

where w is the amount of wage. From the first order conditions of the problem we have:

$$X_{ij} = (1 - \sigma_i)\frac{p_i}{p_j} Q_i \beta_{ij}, \tag{4.4}$$

$$L_i = \frac{\sigma_i p_i Q_i}{w}. \tag{4.5}$$

4.3.2 Consumers

The economy is populated by an infinite number of homogeneous individuals who inelastically supply an amount of labor L. The representative individual has preference CES over the consumption of N goods offered in the economy and chooses consumption c_i to solve the following problem:[12]

$$\begin{aligned} \max \quad & \left[\sum_{i \in N} c_i^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \\ \text{st:} \quad & \sum_{i \in N} p_i c_i = wL, \end{aligned} \tag{4.6}$$

where the parameter θ is the elasticity of substitution between the goods, and w is the amount of wage. The first order conditions of the problem give us the optimal consumption:

$$c_j = \frac{1}{p_j^{\theta}} \frac{wL}{\sum_i p_i^{1-\theta}}. \tag{4.7}$$

4.3.3 Equilibrium

4.3.3.1 Conditions

A competitive equilibrium is a set of prices p_i, wages w, and allocations $c_i, Y_i, L_i, Q_i, X_{ij}$ such that:

1. w and c_i solve the consumer problem, taking p_i as given.

2. w, L_i, and X_{ij} solve the firm's problem, taking p_i as given.

[12] This type of preference function is common in the literature and can be view in Hsieh and Klenow (2009) and Hsieh et al. (2013).

3. Markets clear conditions:

a) The demand for labor by firms must be equal to the supply of individuals:

$$\sum_{i \in N} L_i = L. \tag{4.8}$$

b) The consumption of each good must be equal to the supply of the product intended for consumption:

$$Y_i = c_i, \qquad \forall i \in N. \tag{4.9}$$

c) The supply of product must equal the demand of firms and individuals:

$$Q_i = Y_i + \sum_{j \in N} X_{ij}, \qquad \forall i \in N. \tag{4.10}$$

4.3.3.2 Solution

To solve the equilibrium first we calculate the labor amount L_i and then the prices p_i. First, to calculate the labour we can rewrite Equation (4.5) as: $Q_i = wL_i/(\sigma_i p_i)$, and replace in Equation (4.4) to get the demand of X_{ij} in terms of L_i:

$$X_{ij} = wL_i \left(\frac{1-\sigma_i}{\sigma_i}\right) \frac{\beta_{ij}}{p_j}. \tag{4.11}$$

Replacing Equation (4.11) in Equation (4.2) we have:

$$Q_i = wA_iL_i \left(\frac{1-\sigma_i}{\sigma_i}\right)^{(1-\sigma_i)} \prod_{j \in N} \left(\frac{\beta_{ij}}{p_j}\right)^{(1-\sigma_i)\beta_{ij}}. \tag{4.12}$$

To get the solution of equilibrium we can use Equations (4.9), (4.11) and (4.12) to rewrite Equation (4.10) as:

$$G_iL_i = \sum_{j \in N} B_{ij}L_i + c_i. \tag{4.13}$$

Note that G_i and B_{ij} are simply Q_i and X_{ij} divided by L_i, respectively. The next steps are to divide both sides of the Equation (4.13) by G_i, transform the system of equations into matrix form and solve to find the amount of labor L_i in each sector:

$$\mathbf{L} = \left[\mathbf{I} - \hat{\mathbf{B}}\right]^{-1} \hat{\mathbf{c}}, \tag{4.14}$$

where $\hat{\mathbf{B}}$ and $\hat{\mathbf{c}}$ are B_{ij} and c_i divided by G_i, respectively.

To obtain prices, we substitute Equation (4.12) into (4.5) and take the logarithm, which implies:

$$\ln p_i - \Theta_i p_j = -\ln A_i - \Phi_i. \tag{4.15}$$

We define $\Theta_i = (1-\sigma_i)\sum_j \beta_{ij}$ and $\Phi_i = \ln(1-\sigma_i)^{\sigma_i}\sigma_i^{\sigma_i} + (1-\sigma_i)\sum_j \beta_{ij}\ln\beta_{ij}$. This system of equations can be written in matrix form and solved to find a price vector $\hat{\mathbf{p}}$:

$$\hat{\mathbf{p}} = -\left[\mathbf{I} - \mathbf{\Theta}\right]^{-1}\left[\hat{\mathbf{A}} + \mathbf{\Phi}\right]. \tag{4.16}$$

We then have a vector of sectoral prices that depend on productivity, and constants.

4.3.4 Propagation Channels

Production technology, given by Equation (4.2), takes into account an important characteristic of the productive structure of any economy, which is the interdependence between sectors through the use of intermediate goods. This network allows the impact of a productivity changes in a specific sector to spill over to other sectors of the economy. For example, if a specific sector experiences an improvement in efficiency for a certain reason (innovation, factor reallocation, technological advancement, etc.) and increases its productivity, the sectors that use its goods and services start producing more.

Suppose that there are only two sectors in the economy, A and B. If the productivity of sector A experiences a positive shock, the quantity of intermediate goods produced by sector A increases and the price decreases. The price reduction has a positive impact on the sector B, which starts to demand more inputs from A and consequently increases its production. As a result, the prices of goods produced by sector B decrease, leading sector A to demand more goods from sector B. The magnitude of the effect of the initial shock will depend on the elasticity of the set of intermediate goods with respect to the intermediate good j, β_{ij}, and the elasticity of good in sector i with respect to labor, σ_i.

4.4 Calibration

In this section, we describe the steps of the empirical investigation. First, we discuss how we calibrate the constant parameters of the model presented in the previous section. Then we detail how we calibrate the model and present the result of the adjustment.

4.4.1 Exogenous Calibration

We need to define four parameters of the model, θ, β_{ij}, σ_i and L. The elasticity of substitution in utility function, θ, we follow Hsieh and Klenow (2009) and Hsieh et al. (2013) and set $\theta = 3$. The remaining parameters are calculated using input-output matrices (IO) and Socio Economic Accounts (SEA) data. The elasticity of the set of intermediate goods with respect to the intermediate good j, β_{ij}, is calculated directly using the input-output matrix for each country. Specifically, β_{ij} represents the share of intermediate goods of sector i used in the production of sector j. The elasticity of good in sector i with respect to labor, σ_i, is given by the ratio between the compensation of the employees and the gross output of the industry.[13] Finally, the total amount of labor, L, is associated with the number of people engaged in production in each respective country.

4.4.2 Endogenous Calibration

We calibrated the model for 39 countries in the sample with data from 2014. Our calibration strategy consists of selecting values for sectoral productivity A_i in such a way that the added value per worker resulting from the equilibrium of the model coincides with the added value per worker present in the data. We define the following objective function for our numerical routine:

[13] The calculation of σ_i is a direct consequence of Equation (4.5).

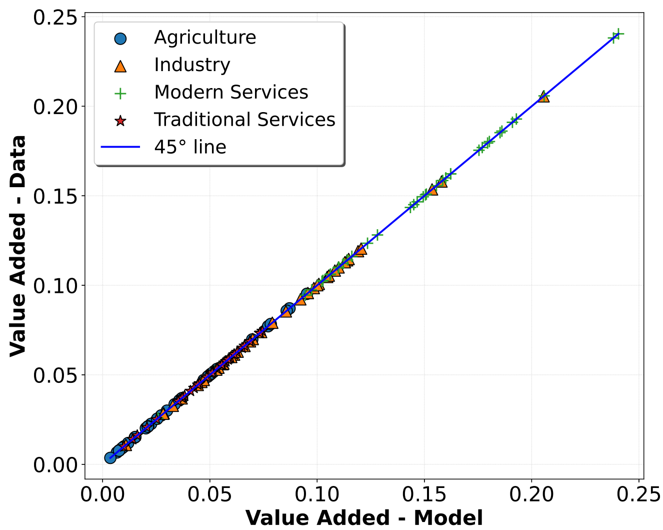
$$\mathfrak{R} = \sum_{i=1}^{N} \left(\frac{VA_i^M - VA_i^T}{VA_i^T} \right)^2 , \tag{4.17}$$

where VA is the value added per worker and the superscripts M and T indicate the model and target statistics. The value added per worker from the model, VA_i^M, is calculated as follows:

$$VA_i^M = \frac{p_i^{USA} c_i}{L_i^M}, \tag{4.18}$$

where p_i^{USA} is USA prices of good i, c_i is the consumption, and L_i^M is the labor amount. Calibration is performed for each country independently of the others. In all, we calibrated 156 parameters, 39 countries multiplied by 4 sectors. Figure 4.3 shows the added value present in the data (y-axis) and the added value resulting from the equilibrium of the model (x-axis). The model fits well with the empirical data, as the points are well fitted to the 45-degree line.

Figure 4.3 – Model Adjustment to Data



4.5 Results

In this section, we present the results of the paper. Initially, we discuss calibrated productivity and show that some model results are in line with empirical facts. We then discuss the results of two counterfactual exercises that we implemented. In the first exercise, we imputed the sectoral productivity of the United States in other countries, verified the effects on the gap in GDP per worker at the sectoral and aggregate level, and discussed how this affects the production chain through intermediate goods. In addition, we discuss the effects of this exercise on aggregate productivity. In the second exercise, we do something similar to the first; the difference is that instead of productivity we impute the elasticity of intermediate goods, of the United States, in other countries, and discuss the effects on price gaps, amount of work, intermediate goods, and GDP per worker.

4.5.1 Total Factor Productivity

In Figure 4.4, we present calibrated sectoral productivity alongside GDP per worker.[14] As expected, the productivity of the four sectors is positively associated with the level of development in the countries, which means that the more developed countries tend to be more productive in all sectors. The relationship between sectoral productivity and GDP per worker is direct, meaning that a potential positive shock in productivity can contribute to its rise.

[14] The calibrated sectoral productivity for each country can be seen in Appendix C.2.

Figure 4.4 – Total Factor Productivity

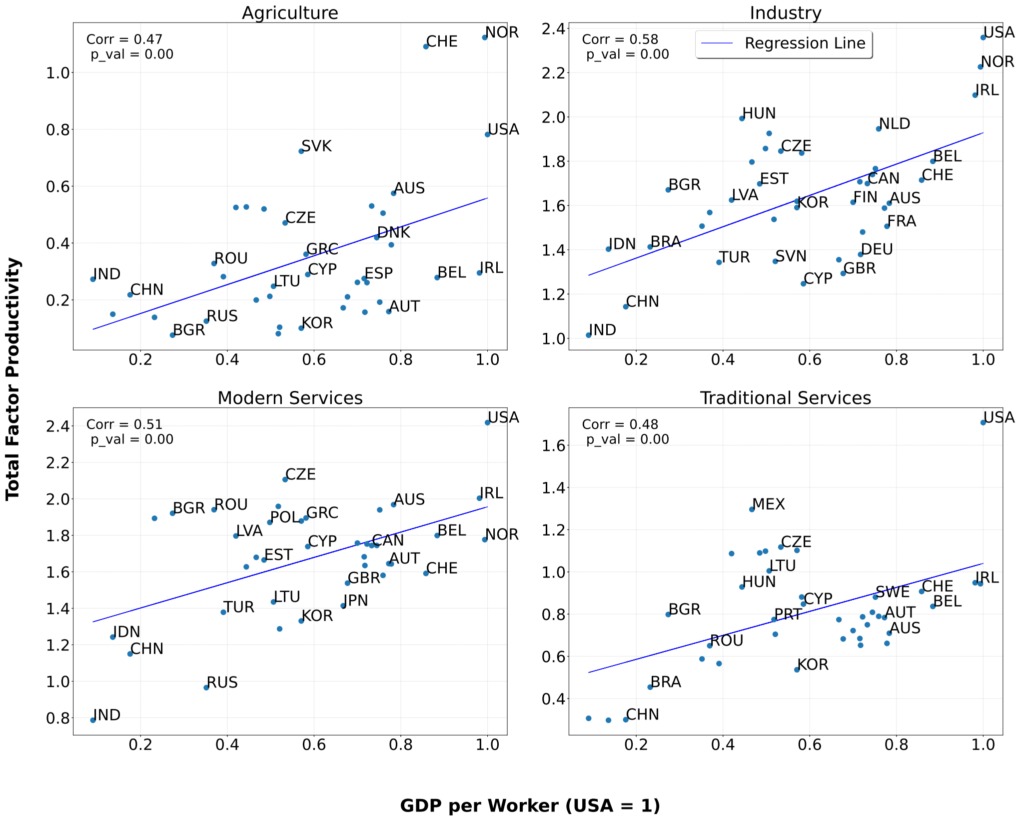


Table 4.2 provides descriptive statistics for the calibrated productivity. It is observed that, on average, the modern services sector is the most productive sector, followed by the industry. This result comes from the fact that modern services encompass the subsectors of real estate activities, financial services, and insurance and reinsurance, and all of these subsectors have value added per worker well above average.

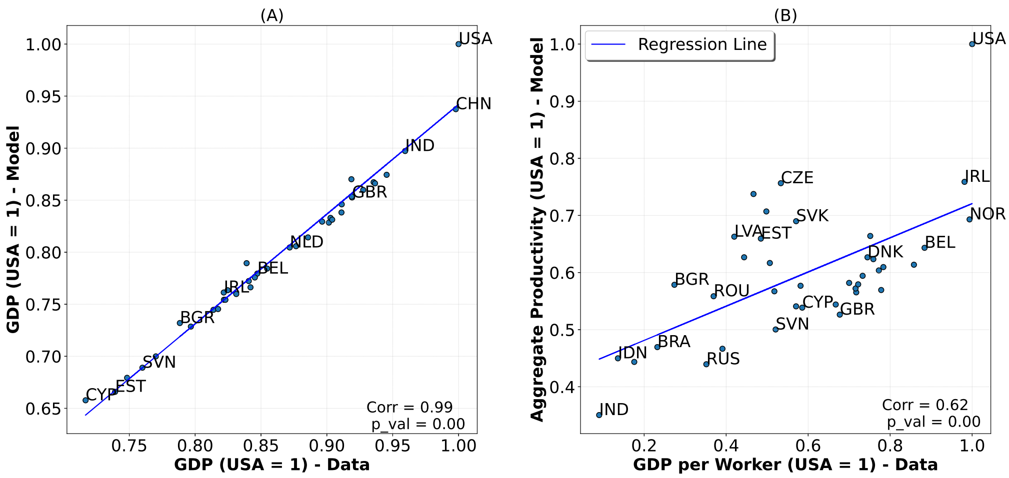
Table 4.2: Descriptive Statistics of Calibrated Sectoral Productivity

Sectors	Mean	Std	Min	25%	50%	75%	Max
Agriculture	0.35	0.25	0.08	0.18	0.28	0.49	1.12
Industry	1.64	0.28	1.01	1.45	1.62	1.80	2.36
Modern Services	1.67	0.31	0.79	1.56	1.74	1.89	2.42
Traditional Services	0.81	0.27	0.30	0.67	0.79	0.94	1.71

Figure 4.5 (A) compares GDP data with GDP and productivity values generated by our model. It is observed that the GDP of the calibrated model fits well with the GDP of the data, and the correlation between these two sets of data is close to unity

and statistically significant at the confidence level 1%. Figure 4.5 (B) compares aggregate productivity and GDP per worker from the data, it is observed that aggregate productivity also has a positive correlation with the level of income of the countries.[15] Note that India, Russia, and China are the countries with the lowest aggregate productivity, while the United States, the Czech Republic, and Ireland are the most productive. Our model also replicates well other important characteristics of economies, for example, the share of intermediate goods, gross product, and labour.[16]

Figure 4.5 – Comparison Between Data and Model Results



Note: We have logarithmized GDP to improve the scale of the figure.

4.5.2 Effects of the Sectoral Productivity Changes

In this section, we conduct a counterfactual exercise in which we insert the sectoral productivity of the United States, one at a time, into each respective sector of other countries. We then assess the effects of these productivity shocks on GDP per worker and aggregate productivity and discuss the key channels through which these changes propagate.

4.5.2.1 GDP per Worker

To investigate which sectors have the greatest capacity to boost economies and reduce the gap in GDP per worker, in relation to the United States, given an improve-

[15] Aggregate productivity is the sum of sectoral productivity weighted by labor share in each sector.
[16] See Figure C.1 in the Appendix for a detailed comparison of these shares between the model and observed data.

ment in productive efficiency, we conducted the following counterfactual exercise: (i) We calculate the productivity gap and the GDP per worker gap at the sectoral and aggregate level;[17] (ii) We insert the sectoral productivity of the United States, one at a time, in each of the analyzed sectors, that is, we reduced the sectoral productivity gap between the United States and the other countries to zero;[18] (iii) We repeat step (i) and measure the percentage change in the productivity gap and the GDP gap per worker at the sectoral and aggregate level. This exercise allows us to measure how much the reduction in the sectoral productivity gap reduces the gap in per capita GDP between the United States and other countries at the sectoral and aggregate level.

Figure 4.6 illustrates the results of this exercise at the aggregate level. The x-axis presents the percentage change in the GDP gap per worker, while the y-axis presents the percentage change in the productivity gap. Points below the 45-degree line indicate that the reduction in the productivity gap has led to a less than proportional reduction in the GDP per worker gap. Note that in all sectors, except agriculture, the reduction in the output gap per worker was more than proportional in most countries. It is also noted that there is a positive correlation between both variables, that is, where there have been greater reductions in the productivity gap, there have also been greater reductions in the GDP per worker gap.

The countries that benefit the most from closing the sectoral productivity gap, in general, are the less developed countries, especially in industry and both traditional and modern services. In India, for example, reductions of 57%, 82%, and 67% in the productivity gaps of these three sectors resulted in aggregate reductions of 89%, 84%, and 71% in the GDP gaps per worker, respectively.

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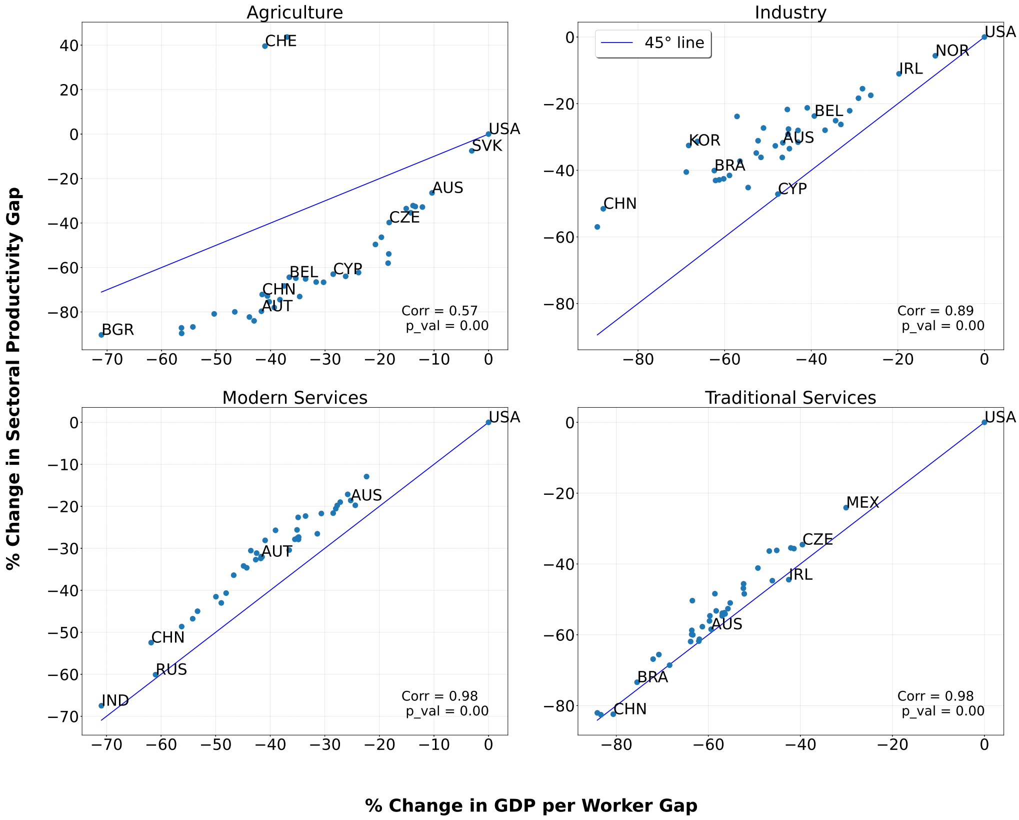
[17] Recall that the GDP per worker gap is calculated as the ratio between the GDP per worker of the United States and that of the other countries in the sample. The productivity gap is calculated in a similar way.

[18] The productivity of United States in agriculture, industry, modern services, and traditional services is 0.78, 2.36, 2.42, 1.71, respectively.

Figure 4.6 – Percentual Changes in per Worker GDP Gap Given a Percentual Change in Productivity Gap



Note: Points below the 45-degree line suggest that reducing the productivity gap results in a less than proportional decrease in the GDP per worker gap.

Table 4.3 presents the average results of this counterfactual exercise. The first column of the table displays the average percentage reduction in the productivity gap. The second and third columns show the average percentage reduction in the GDP gap per worker at the sectoral and aggregate level, respectively. The last two columns are the ratios between columns two and three, and column one. Both columns illustrate the proportional effect of variations in the productivity gap on the variation in the GDP gap per worker, at the sectoral and aggregate levels, respectively. In agriculture, for instance, the 55.3% reduction in the productivity gap resulted in average reductions of 87.28% and 31.72% in the GDP gap per worker at the sectoral and aggregate level, respectively. On the other hand, in industry, the average reduction of 30.58% in the productivity gap reduced 75.72% and 47.39%, on average.

When we look at column four, we notice that the sectoral GDP per worker gap responds more than proportionally to variations in the sectoral productivity gap. If we combine with the results provided in the fifth column, we note that there is a clear order of the average impact of sectoral productivity changes on the GDP per worker gap at sectoral and aggregate levels. The impact of productivity changes in the industrial sector is greater than in the modern services sector, which in turn exceeds the impact in traditional services and is ultimately greater than in the agricultural sector.

Table 4.3: Average Percentage Change in Gaps in Productivity and GDP per Capita

	(1)	(2)	(3)	(4)	(5)
	% Change in Gaps				
Sectors	Productivity	**Sectoral** Per Worker GDP	Per Worker GDP	Ratio 1 (2)/(1)	Ratio 2 (3)/(1)
Agriculture	-55.30	-87.28	-31.72	1.57	0.57
Industry	-30.58	-75.72	-47.39	2.47	1.55
Modern Services	-30.89	-54.52	-39.11	1.76	1.27
Traditional Services	-52.76	-82.99	-56.70	1.57	1.07

4.5.2.2 Intermediate Goods as Channels for Propagating Changes in Productivity

This effect in GDP per worker gap can be attributed to two main factors. First, by increasing the productivity of a sector there is a reallocation of workers in the economy; that is, the positive variation in the productivity of a sector is associated with a positive variation in labor share. The shift of labor from low productivity sectors, for example agriculture, to high productivity sectors such as modern services and industry is a driver to further increase the final product of economies.

Second, interdependence between sectors causes the effect of the impact of a productivity change on a specific sector to spread to other sectors of the economy. For example, in the sector that receives the productivity change, prices decrease, so there is greater demand for intermediate goods. Hence, sectors that use the now more productive goods and services as intermediate inputs will also benefit indirectly, and so on. In Table 4.4 we present the average percentage change in intermediate inputs after sectoral productivity shocks, the columns of the table indicate the sector that received the shock, while the rows indicate the average percentage change in intermediate inputs of the respective sector.

We highlight two facts. First, a productivity change in a specific sector has a greater effect on the supply of intermediate goods within that same sector. For example, closing the productivity gap in relation to the United States in agriculture results in an average increase of 530.31% in the supply of intermediate goods within the same sector. Second, productivity shocks in the industry and traditional services sectors were the ones that most stimulated the supply of intermediate goods, both for themselves and for other sectors of the economy, on average.

Table 4.4: Average Percentage change in Intermediate Inputs After Sectoral Productivity Shock

Sectors	Agriculture	Industry	Modern Services	Traditional Services
Agriculture	530.31	155.91	5.42	52.59
Industry	13.82	391.65	11.11	86.02
Modern Services	0.26	71.42	115.63	89.93
Traditional Services	2.32	62.90	13.98	335.39

This high effect of productivity changes in industry and traditional services, in the production chain, can be attributed to the fact that both sectors are, on average, the most central. Central sectors are those that are most closely linked in production networks with other sectors, which implies that positive productivity changes in these sectors tend to have a greater impact on the production chain and GDP compared to more peripheral sectors.

To measure how central a sector is, we calculated the Bonacich-Katz centrality index, which measures the importance of a sector as a supplier to the economy and has been applied in the recent literature on the diffusion of macroeconomic shocks (ACEMOGLU et al., 2012; CARVALHO, 2014; GRASSI; SAUVAGNAT, 2019). The centrality index is, on average, higher in traditional service sectors and industry, 0.75 in both. Agriculture and modern services have a Bonacich-Katz centrality index, on average, equal to 0.32 and 0.41, respectively.[19]

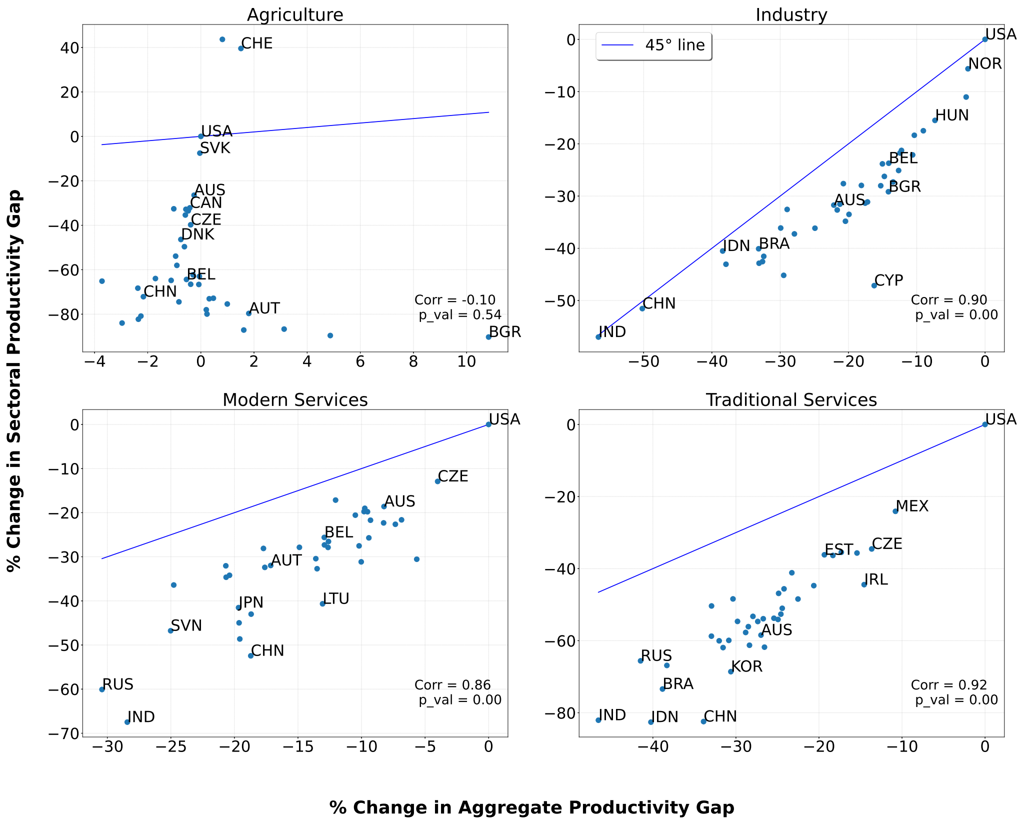
[19] In Appendix C.2 we provide the method for calculating the Bonacich-Katz centrality index.

4.5.2.3 Aggregate Productivity

In section 4.5.2.1, we assessed the effects of productivity changes on GDP per worker at both the sectoral and aggregate levels. In this section, we examine the effects of the same exercise on aggregate productivity. Aggregate productivity is simply the sum of productivities, weighted by labor share.

Figure 4.7 illustrates the results. The x-axis shows the percentage change in the aggregate productivity gap, while the y-axis presents the percentage change in the productivity gap. Points below the 45-degree line indicate that the reduction in the productivity gap led to a less than proportional reduction in the aggregate productivity gap. It is noticeable that in all sectors, except agriculture, there is a strong positive correlation between the percentage changes in sectoral and aggregate productivity gaps. In other words, we have a result analogous to that of the previous section, where a greater reduction in the sectoral productivity gap also led to a greater reduction at the aggregate level.

Figure 4.7 – Percentual Changes in Aggregate Productivity Gap Given a Percentual Change in Sectoral Productivity Gap



Note: Points below the 45-degree line indicate that the reduction in the productivity gap led to a less than proportional reduction in the aggregate productivity gap.

Table 4.5, analogous to the table presented in the previous section, shows the average results of the exercise. Industry had a greater proportional effect (see column 5), that is, a 30.58% reduction in the sectoral productivity gap led to a 20.96% reduction in the productivity gap at the aggregate level.

Table 4.5: Average Percentage Change in Gaps in Sectoral and Aggregate Productivity

	(1)	(2)	(3)	(4)	(5)
	% Change in Gaps				
Sectors	Productivity	**Sectoral** Weighted Productivity	Aggregate Productivity	Ratio 1 (2)/(1)	Ratio 2 (3)/(1)
Agriculture	-55.30	-74.92	-0.03	1.35	0.00
Industry	-30.58	-41.63	-20.96	1.36	0.68
Modern Services	-30.89	-44.15	-14.26	1.42	0.46
Traditional Services	-52.76	-58.72	-26.56	1.11	0.50

When we compare this exercise with the one from the previous section, we notice an interesting particularity in the services sector. The modern services sector has a greater average impact on GDP per worker gap when subjected to productivity changes compared to traditional services. On the other hand, the traditional services sector has a greater average impact on aggregate productivity when subjected to productivity changes, compared to modern services. This is due to the fact that, on average, the traditional services sector concentrates most of the labor share; therefore, it has a greater weight in the calculation of aggregate productivity, and this causes productivity changes in this sector as well have greater weight.[20]

In the case of agriculture, productivity changes have little effect on aggregate productivity. This is because in this sector, labor participation and productivity are relatively small compared to other sectors. As can be seen in Table 4.5, on average a reduction of 55.3% in the sectoral productivity gap only resulted in a reduction of 0.03% in the aggregate. Column 5 shows that the proportional effect was close to zero.

[20] On average, traditional services concentrates 44% of labor share.

4.5.3 Changing Elasticity of Intermediate Goods

In this section, we analyze what would happen to the economies of the sample countries if their production structures were to converge to that of the United States. Therefore, we conduct a counterfactual exercise similar to that in the previous section. However, in this new exercise, instead of inserting the productivity of the United States to the other countries, we insert the elasticity of the set of intermediate goods with respect to the intermediate good i, β_{ij}. Specifically, by proceeding in this way, we are making the importance of good j in the production of good i equal to that of the United States.

In Table 4.6, we present the sectoral average shares of intermediate inputs before and after the exercise, along with those of the United States. It can be seen that the average share of intermediate inputs before the exercise is higher in the industry (53%), followed by traditional services (26%). However, after the exercise, the share of intermediate inputs becomes more similar to that of the United States. In other words, the industry loses its share, and economies become more service-oriented, with both modern and traditional services gaining a larger share. Note that what we did was reduce the gap in the share of intermediate inputs to almost zero.

Table 4.6: Share of Intermediate Inputs

	Average		
Sectors	Before Change	After Change	USA
Agriculture	0.01	0.01	0.01
Industry	0.53	0.34	0.36
Modern Services	0.21	0.30	0.28
Traditional Services	0.26	0.35	0.35

Table 4.7 presents the average percentage change in the sectoral gaps in prices, labor, intermediate inputs, and GDP per worker given this counterfactual exercise. It is noticeable that there has been a considerable increase in the gaps in labor, intermediate inputs, and sectoral GDP in agriculture and industry. In other words, this structural change that altered the importance of intermediate inputs in production resulted in a negative average effect on the economies.

This is due to the fact that the structural change was carried out without the necessary increase in productivity. Specifically, in countries with highly efficient agricultural and/or industrial sectors, the structural change led to a reduction in the quantity of labor and intermediate inputs, and consequently they began to produce less, resulting in an increased gap.

In the modern services sector, the opposite occurred, which means that the structural change benefited this sector. In this case, the quantity of labor and intermediate inputs increased and the gap in sectoral GDP decreased. Finally, the traditional services sector underwent little change, but there was an increase in the gap in sectoral GDP.

Table 4.7: Average Percentage Change in Gaps

Sectors	Prices	Labor	Intermediate Inputs	GDP per Worker
Agriculture	-8.21	64.30	118.19	79.15
Industry	-14.45	59.74	149.25	84.37
Modern Services	3.04	-27.87	-30.67	-22.07
Traditional Services	-8.51	-10.21	-1.31	10.59

4.6 Final Remarks

In this article we develop a general equilibrium model to quantitatively evaluate the effects of productivity changes and changes in the productive structure on the income gap in developed and developing countries. We used WIOD data from 2014 and calibrated the model for 39 countries. We conducted two counterfactual exercises, in the first we imputed the productivity of the United States in other countries and evaluated the effects on the income gap per worker, on aggregate productivity, and on the supply of intermediate inputs. In the second exercise, we impute the elasticity of intermediate goods in other countries and evaluate the effects on prices, supply of intermediate goods, number of workers, and sectoral income per worker.

Our findings show that productivity in modern services is, on average, higher than in other sectors. However, closing the manufacturing productivity gap, relative to the United States, results in a greater average reduction in the gaps in income per worker and aggregate productivity gaps. Furthermore, industry is, on average, the most central sector; therefore, this sector has a greater capacity to transmit productivity changes and, consequently, to stimulate production in other sectors.

We also show that if economies became more service-oriented, without the necessary increase in productivity, this would further increase the income gap per worker. This arises from the fact that some countries have a very productive agricultural and/or industrial sector, therefore, a structural change that causes these countries to produce more intermediate inputs in the service sectors causes these economies to move resources from more productive sectors to the services sector, which in turn harms economic development. A future avenue of research is to identify the drivers that cause economies to become more service-oriented.

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APPENDIX A – From Chapter 2

A.1 Descriptive Statistics and Evolution of Variables

Figure A.1 – Evolution of Time Series Used in the Study - 1996:2018

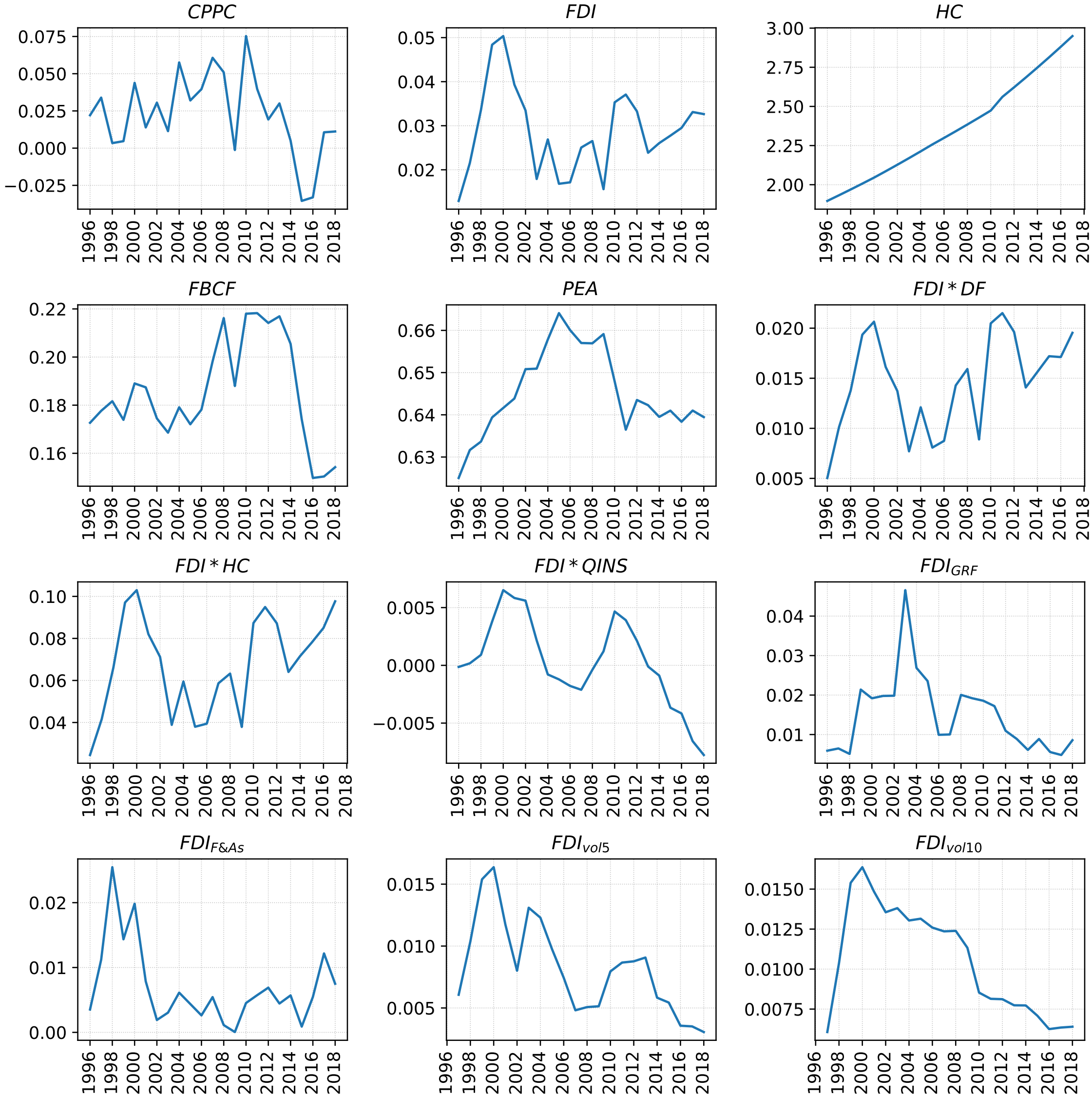


Table A.1 – Descriptive Statistics of Variables Used in the Study

Statistics	$CPPC$	FDI	HC	$FBCF$	LAB	$FDI*DF$
Mean	0.0229	0.0289	2.3586	0.1851	0.6453	0.0145
Median	0.0221	0.0277	2.3200	0.1791	0.6423	0.0150
Maximum	0.0753	0.0503	2.9493	0.2183	0.6641	0.0215
Minimum	−0.0355	0.0129	1.8965	0.1497	0.6250	0.0050
Std. Dev.	0.0271	0.0098	0.3224	0.0215	0.0102	0.0048
Statistics	$FDI * HC$	$FDI * QINS$	FDI_{GRF}	$FDI_{F\&As}$	FDI_{vol5}	FDI_{vol10}
Mean	0.0676	0.0003	0.0149	0.0070	0.0082	0.0105
Median	0.0687	−0.0001	0.0110	0.0055	0.0080	0.0109
Maximum	0.1030	0.0065	0.0466	0.0255	0.0164	0.0164
Minimum	0.0245	−0.0078	0.0048	0.0001	0.0031	0.0061
Std. Dev.	0.0232	0.0038	0.0097	0.0061	0.0038	0.0034

Source: Research results.

Notes: $CPPC$ = per capita GDP growth rate; FDI = foreign direct investment; HC = human capital; $FBCF$ = gross fixed capital formation; LAB = economically active population; $FDI * DF$ = FDI multiplied by financial development; $FDI * HC$ = FDI multiplied by human capital; $FDI * QINS$ = FDI multiplied by institutional quality; FDI_{GRF} = greenfield FDI; $FDI_{F\&As}$ = FDI by mergers and acquisitions ($F\&As$); FDI_{vol5} = 5-period moving standard deviation of FDI; FDI_{vol10} = 10-period moving standard deviation of FDI.

A.2 Model Specification Tests

Table A.2 – Augmented Dickey-Fuller Unit Root Test for Selected Variables

Variable	Deterministic Terms	Lags	t-Statistic	Test p-value
$CPPC$	I, T	0	-3.4900	0.0643
FDI	I, T	0	-2.7046	0.2477
ΔFDI	I, T	0	-4.3476	0.0026
HC	I, T	0	0.6965	0.9992
ΔHC	I, T	0	-4.0228	0.0234
$FBCF$	I, T	0	-1.2436	0.8764
$\Delta FBCF$	I, T	0	-5.8656	0.0004
PEA	I, T	0	-1.2697	0.8700
ΔPEA	I, T	0	-4.9239	0.0034
$FDI * DF$	I, T	0	-2.8855	0.1854
$\Delta(FDI * DF)$	I, T	0	-4.8952	0.0039
$FDI * HC$	I, T	0	-2.5523	0.3027
$\Delta(FDI * HC)$	I, T	0	-4.4266	0.0103
$FDI * QINS$	I, T	2	-3.5695	0.0588
FDI_{GRF}	I, T	0	-2.6271	0.2727
ΔFDI_{GRF}	I, T	0	-6.0690	0.0003
$FDI_{F\&As}$	I, T	0	-2.9544	0.1652
$\Delta FDI_{F\&As}$	I, T	0	-5.2559	0.0017
FDI_{vol5}	I, T	0	-3.4321	0.1739
ΔFDI_{vol5}	I, T	0	-3.5422	0.0618
FDI_{vol10}	I, T	1	-6.6397	0.0002

Source: Research results.

Notes: $CPPC$ = per capita GDP growth rate; FDI = foreign direct investment; HC = human capital; $FBCF$ = gross fixed capital formation; PEA = economically active population; $FDI * DF$ = FDI multiplied by financial development; $FDI * HC$ = FDI multiplied by human capital; $FDI * QINS$ = FDI multiplied by institutional quality; FDI_{GRF} = greenfield FDI; $FDI_{F\&As}$ = FDI by mergers and acquisitions ($F\&As$); FDI_{vol5} = 5-period moving standard deviation of FDI; FDI_{vol10} = 10-period moving standard deviation of FDI.

I: Indicates the presence of intercept in the test equation

T: Indicates the presence of trend in the test equation

Δ: Indicates that the variable is in first difference

Table A.3 – Model Specification Selection Criterion - Specification 1

Lag	AIC	SC	HQ
0	-41.0422	-40.7447	-40.9721
1	-42.1849	-40.1019	-41.6942
2	-44.7299*	-40.8616*	-43.8186*

Source: Research results.

Table A.4 – Model Specification Selection Criterion - Specification 2

Lag	AIC	SC	HQ
0	-42.5464	-40.2488	-42.4763
1	-43.2567	-41.1739	-42.7661
2	-44.6830*	-42.8147*	-43.7717*

Source: Research results.

Table A.5 – Model Specification Selection Criterion - Specification 3

Lag	AIC	SC	HQ
0	-42.0119	-41.7137	-41.9615
1	-43.9222	-41.8345	-43.5689
2	-54.5132*	-50.6359*	-53.8569*

Source: Research results.

Table A.6 – Model Specification Selection Criterion - Specification 4

Lag	AIC	SC	HQ
0	-38.6906	-38.6205	-38.3931
1	-38.9127	-38.4221	-38.8298
2	-40.9794*	-40.0685*	-39.1112*

Source: Research results.

Table A.7 – Model Specification Selection Criterion - Specification 5

Lag	AIC	SC	HQ
0	-31.2738	-31.2154	-31.0258*
1	-31.6117	-31.2612	-30.1239
2	-32.4094*	-31.7668*	-29.6817

Source: Research results.

Table A.8 – Model Specification Selection Criterion - Specification 6

Lag	AIC	SC	HQ
0	-31.4778	-31.4194	-31.2298*
1	-32.5496	-32.1991	-31.0618
2	-33.0114*	-32.3688*	-30.2837

Source: Research results.

Table A.9 – Model Specification Selection Criterion - Specification 7

Lag	AIC	SC	HQ
0	-40.9657	-40.9152	-40.6674
1	-41.3123*	-40.9589*	-41.2246*

Source: Research results.

Table A.10 – Model Specification Selection Criterion - Specification 8

Lag	AIC	SC	HQ
0	-42.3389	-42.2885	-42.0407
1	-43.8131*	-43.4597*	-42.7253*

Source: Research results.

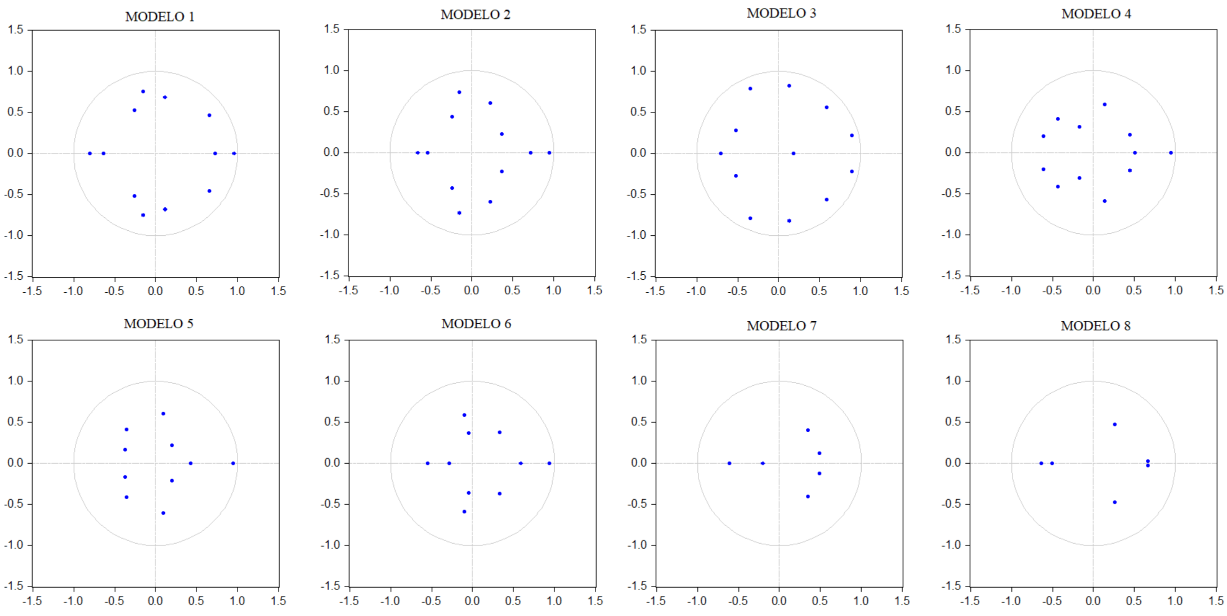
Notes: Asterisk (*) indicates the lag order selected by the criterion

AIC: Akaike Information Criterion

SC: Schwarz Criterion

HQ: Hannan-Quinn Criterion

Figure A.2 – Roots of the Characteristic Polynomial: Specifications 1, 2, 3, 4, 5, 6, 7, and 8



A.3 Estimation of the Greenfield FDI

The variable *FDI greenfield* (FDI_{GRF}) was taken from the United Nations Conference on Trade and Development (UNCTAD) database. It's worth noting that data for this variable is only available from 2003 onwards. Since the research period for this study is from 1996 to 2018, it was necessary to estimate the values of FDI_{GRF} for the period from 1996 to 2002. To achieve this, the procedure outlined by Harms and Méon (2018) was used, which involves estimating a regression where the dependent variable is FDI_{GRF} available in the UNCTAD database (FDI_{GRF}^{UNCTAD}), and the independent variable is given by[1] $FDI - FDI_{F\&As}$, referred to here as FDI_{GRF}^{Calc}. Thus, we have:

$$FDI_{GRF}^{UNCTAD} = 0.6258 FDI_{GRF}^{Calc} \tag{A.1}$$

Therefore, the synthetic measure[2] of FDI_{GRF} used in this study is given by:

$$\begin{cases} 0.6258 FDI_{GRF}^{Calc} \text{ between the years 1996 and 2002} \\ FDI_{GRF}^{UNCTAD} \text{ between the years 2003 and 2018} \end{cases} \tag{A.2}$$

A.4 Estimation of FDI Volatility

Several approaches can be adopted for calculating the volatility of international capital flows. Broto, Díaz-Cassou and Erce (2011) suggest three of them. The first approach involves estimating the ARIMA model using the desired series and then using the residuals of this estimation to calculate a proxy for the volatility of this series. Since the Brazilian FDI series between 1996 and 2018 is not an autoregressive process, this model was not used. The second approach would be to use the GARCH model; however, the FDI series is not a heteroskedastic process. Therefore, the third approach proposed by Broto, Díaz-Cassou and Erce (2011) was chosen, which involves calculating the moving standard deviation of the series in period t using the following equation:

$$FDI_t^{vol} = \left(\frac{1}{n} \sum_{j=t-(n-1)}^{t} (FDI_t - \mu)^2 \right)^{1/2} \tag{A.3}$$

where $\mu = 1/n \sum_{j=t-(n-1)}^{t} FDI_t$. In this study, the moving standard deviation over five and ten periods was used.

[1] $FDI_{F\&As}$ refers to FDI through Mergers and Acquisitions. The assumption here is that $FDI = FDI_{GRF} + FDI_{F\&As}$.

[2] For convenience, the term FDI_{GRF} is used throughout the text.

APPENDIX B – From Chapter 3

B.1 Descriptive Statistics

Table B.1 – Descriptive statistics of teachers' hourly wages by state

State	Relative Wage	Mean	1° Quartile	Median	3° Quartile	Variance	Income Group
AC	1.57	17.53	9.72	14.29	23.81	10.46	Middle Income
AL	1.45	16.04	9.38	13.91	20.37	9.65	Low Income
AM	1.30	16.13	9.52	14.29	20.24	8.63	Middle Income
AP	1.48	19.77	13.17	17.80	23.53	10.03	Middle Income
BA	1.33	15.40	8.33	11.90	17.86	11.97	Low Income
CE	1.21	14.04	8.33	11.90	15.87	11.17	Low Income
DF	1.49	27.93	13.69	23.81	35.71	17.42	High Income
ES	1.29	18.16	9.68	15.01	21.33	12.99	High Income
GO	1.42	19.30	10.19	14.29	22.55	15.18	Middle Income
MA	1.30	15.93	8.93	11.90	20.40	12.50	Low Income
MG	1.37	18.42	9.52	14.29	21.65	13.78	Middle Income
MS	1.45	21.84	11.11	17.86	26.19	16.22	High Income
MT	1.31	18.93	11.90	17.06	21.43	10.58	High Income
PA	1.50	17.81	9.38	14.29	21.71	13.82	Low Income
PB	1.37	17.13	9.04	12.50	21.60	12.55	Low Income
PE	1.29	14.99	7.28	11.43	19.05	11.57	Low Income
PI	1.28	14.24	9.52	13.10	15.67	7.72	Low Income
PR	1.36	21.04	11.90	17.27	23.81	14.86	High Income
RJ	1.33	20.00	9.52	15.87	23.81	15.05	High Income
RN	1.24	15.53	7.37	11.90	18.45	13.25	Low Income
RO	1.25	16.21	10.39	14.07	17.86	10.30	Middle Income
RR	1.62	22.34	9.72	20.22	29.17	14.21	Middle Income
RS	1.38	20.40	10.84	15.16	23.81	15.12	High Income
SC	1.21	18.15	11.90	14.88	20.83	11.36	High Income
SE	1.70	19.61	9.40	16.67	26.19	13.52	Middle Income
SP	1.13	18.61	9.52	14.88	23.15	14.07	High Income
TO	1.30	17.32	9.38	14.58	19.05	13.09	Middle Income

Source: Elaborated by the authors with data from PNAD 2015.
Notes: Relative wage is the average hourly wage of teachers divided by the average hourly wage of other six occupations. Acre (AC), Alagoas (AL), Amapá (AP), Amazonas (AM), Bahia (BA), Ceará (CE), Distrito Federal(DF), Espírito Santo (ES), Goiás (GO), Maranhão (MA), Mato Grosso (MT), Mato Grosso do Sul (MS), Minas Gerais (MG), Pará (PA), Paraíba (PB), Paraná (PR), Pernambuco (PE), Piauí (PI), Rio de Janeiro (RJ), Rio Grande do Norte (RN), Rio Grande do Sul (RS), Rondônia (RO), Roraima (RR), Santa Catarina (SC), São Paulo (SP), Sergipe (SE), Tocantins (TO).

Table B.2 – Logarithm of average hourly wages by occupation and state

	Managers	Sciences and arts	Middle-level technicians	Service sector	Agriculture	Industrial production and services	Teachers
AC	2.87	2.86	2.19	2.00	2.04	2.06	2.86
AL	2.68	2.99	2.29	1.95	2.06	1.95	2.77
AM	2.97	3.05	2.46	2.02	1.91	2.07	2.78
AP	3.11	3.13	2.50	2.08	1.86	2.10	2.98
BA	2.81	3.10	2.37	1.92	1.78	2.02	2.73
CE	2.83	3.13	2.44	1.92	1.53	1.87	2.64
DF	3.42	3.47	2.97	2.36	2.24	2.36	3.33
ES	2.92	3.21	2.74	2.06	2.03	2.27	2.90
GO	2.97	3.02	2.64	2.14	2.24	2.26	2.96
MA	3.10	2.99	2.44	1.99	1.75	1.95	2.77
MG	2.92	3.20	2.63	2.04	2.00	2.17	2.91
MS	3.05	3.27	2.70	2.14	2.29	2.26	3.08
MT	2.93	3.22	2.56	2.16	2.37	2.36	2.94
PA	2.94	2.92	2.48	1.96	2.00	1.99	2.88
PB	2.80	3.24	2.45	1.95	1.91	2.01	2.84
PE	2.91	3.07	2.36	1.89	1.72	1.94	2.71
PI	2.92	3.00	2.29	1.88	1.65	1.92	2.66
PR	3.10	3.23	2.79	2.23	2.26	2.32	3.05
RJ	3.03	3.42	2.65	2.15	1.88	2.27	3.00
RN	2.97	3.13	2.51	2.00	1.77	1.92	2.74
RO	2.89	3.00	2.56	2.08	2.20	2.28	2.79
RR	3.04	3.26	2.66	2.03	1.80	2.11	3.11
RS	3.05	3.24	2.68	2.19	2.22	2.22	3.02
SC	3.01	3.18	2.73	2.30	2.33	2.34	2.90
SE	2.92	3.02	2.39	1.91	1.65	1.97	2.98
SP	3.25	3.30	2.83	2.22	2.22	2.35	2.92
TO	2.90	3.20	2.54	2.10	2.01	2.19	2.85

Source: Elaborated by the authors with data from PNAD 2015.

Table B.3 – Average years of schooling by occupation and state

	Managers	Sciences and arts	Middle-level technicians	Service sector	Agriculture	Industrial production and services	Teachers
AC	9.82	10.82	10.69	8.71	4.26	6.79	14.40
AL	10.33	13.24	11.91	7.83	3.70	6.20	14.13
AM	11.48	13.48	11.24	9.09	4.39	8.40	14.20
AP	10.82	13.50	11.84	8.88	4.92	7.38	13.95
BA	11.09	13.51	11.27	8.80	3.52	7.19	13.69
CE	10.57	13.45	11.46	8.65	3.69	7.44	14.19
DF	12.76	14.18	11.88	9.55	5.61	7.90	14.47
ES	11.07	13.85	11.83	8.82	5.82	7.91	14.59
GO	11.69	13.43	11.47	8.77	5.85	7.73	14.45
MA	11.35	13.62	11.27	8.60	4.32	7.07	13.36
MG	11.57	13.97	11.54	8.62	5.02	7.41	14.11
MS	11.71	13.98	11.48	8.58	5.39	7.42	14.11
MT	11.08	13.79	11.37	9.14	5.71	7.54	14.39
PA	10.82	12.58	10.68	8.63	4.05	7.01	14.09
PB	11.88	13.82	10.81	8.51	3.41	6.29	14.32
PE	11.09	14.06	11.50	8.58	4.38	7.02	14.13
PI	11.03	13.35	11.37	8.21	4.05	6.13	14.27
PR	11.93	13.81	11.79	9.01	6.32	8.02	14.29
RJ	11.99	14.17	11.76	9.02	5.29	8.16	14.02
RN	10.47	13.57	11.13	8.85	3.67	7.09	14.03
RO	10.08	14.03	10.69	8.78	5.45	7.03	14.28
RR	10.83	12.95	12.05	9.34	4.83	7.23	14.16
RS	11.66	13.92	11.73	8.98	6.10	7.75	14.42
SC	11.60	13.69	11.57	9.20	6.57	8.18	14.37
SE	11.07	13.68	11.11	8.53	3.27	6.30	14.20
SP	12.48	14.27	12.02	9.18	6.46	8.38	14.09
TO	10.40	13.34	11.34	8.98	5.13	8.05	14.20

Source: Elaborated by the authors with data from PNAD 2015.

Table B.4 – Share of workers in each occupation by state

	Managers	Sciences and arts	Middle-level technicians	Service sector	Agriculture	Industrial production and services	Teachers
AC	0.04	0.03	0.05	0.42	0.13	0.25	0.09
AL	0.04	0.04	0.07	0.41	0.12	0.25	0.07
AM	0.05	0.05	0.08	0.38	0.07	0.29	0.08
AP	0.04	0.03	0.07	0.44	0.07	0.25	0.10
BA	0.05	0.04	0.06	0.45	0.08	0.26	0.06
CE	0.05	0.03	0.06	0.44	0.05	0.31	0.07
DF	0.06	0.10	0.10	0.48	0.01	0.17	0.08
ES	0.07	0.06	0.07	0.35	0.12	0.29	0.05
GO	0.05	0.05	0.06	0.42	0.08	0.29	0.05
MA	0.04	0.04	0.06	0.37	0.14	0.27	0.09
MG	0.06	0.06	0.06	0.39	0.10	0.28	0.06
MS	0.06	0.06	0.05	0.38	0.12	0.27	0.06
MT	0.05	0.05	0.06	0.35	0.16	0.28	0.05
PA	0.03	0.04	0.05	0.44	0.11	0.27	0.06
PB	0.05	0.05	0.07	0.42	0.08	0.25	0.08
PE	0.05	0.06	0.07	0.46	0.05	0.25	0.06
PI	0.04	0.03	0.05	0.40	0.10	0.30	0.08
PR	0.08	0.07	0.07	0.36	0.07	0.29	0.06
RJ	0.05	0.08	0.08	0.46	0.01	0.25	0.06
RN	0.06	0.05	0.07	0.42	0.06	0.26	0.07
RO	0.06	0.04	0.05	0.35	0.16	0.28	0.06
RR	0.05	0.03	0.07	0.39	0.11	0.24	0.11
RS	0.06	0.08	0.08	0.39	0.06	0.28	0.05
SC	0.08	0.06	0.07	0.32	0.09	0.31	0.06
SE	0.04	0.04	0.05	0.43	0.14	0.25	0.06
SP	0.07	0.09	0.08	0.41	0.03	0.27	0.05
TO	0.05	0.04	0.05	0.33	0.21	0.23	0.09

Source: Elaborated by the authors with data from PNAD 2015.

B.2 Calibrated $\tau's$ and $A's$ to 2015 and 2003

Table B.5 – Labor market frictions τ^{w}_{ir} - 2015

State	Managers	Sciences and arts	Middle-level technicians	Service sector	Agriculture	Industrial production and services	Teachers	**Mean friction by state**	Income Level
AC	0.56	0.53	0.43	0.43	0.50	0.47	0.53	0.49	Middle Income
AL	0.56	0.58	0.49	0.45	0.54	0.47	0.55	0.52	Low Income
AM	0.56	0.54	0.48	0.42	0.45	0.45	0.50	0.49	Middle Income
AP	0.56	0.53	0.46	0.41	0.41	0.43	0.51	0.47	Middle Income
BA	0.56	0.57	0.48	0.42	0.44	0.47	0.52	0.50	Low Income
CE	0.56	0.58	0.50	0.41	0.35	0.42	0.50	0.47	Low Income
DF	0.56	0.54	0.50	0.43	0.47	0.45	0.52	0.50	High Income
ES	0.56	0.57	0.54	0.44	0.49	0.51	0.53	0.52	High Income
GO	0.56	0.54	0.51	0.45	0.53	0.50	0.53	0.52	Middle Income
MA	0.56	0.51	0.45	0.38	0.38	0.39	0.47	0.45	Low Income
MG	0.56	0.57	0.52	0.43	0.49	0.49	0.53	0.51	Middle Income
MS	0.56	0.56	0.51	0.43	0.53	0.48	0.53	0.52	High Income
MT	0.56	0.57	0.50	0.46	0.56	0.53	0.53	0.53	High Income
PA	0.56	0.53	0.49	0.41	0.48	0.44	0.52	0.49	Low Income
PB	0.56	0.60	0.51	0.43	0.49	0.47	0.54	0.51	Low Income
PE	0.56	0.56	0.47	0.39	0.40	0.43	0.50	0.47	Low Income
PI	0.56	0.54	0.45	0.38	0.38	0.42	0.48	0.46	Low Income
PR	0.56	0.55	0.52	0.45	0.52	0.49	0.52	0.52	High Income
RJ	0.56	0.59	0.50	0.44	0.44	0.49	0.53	0.51	High Income
RN	0.56	0.56	0.49	0.41	0.41	0.41	0.49	0.48	Low Income
RO	0.56	0.55	0.51	0.45	0.54	0.52	0.51	0.52	Middle Income
RR	0.56	0.56	0.50	0.41	0.41	0.45	0.54	0.49	Middle Income
RS	0.56	0.56	0.51	0.45	0.52	0.48	0.52	0.51	High Income
SC	0.56	0.56	0.52	0.48	0.54	0.51	0.51	0.53	High Income
SE	0.56	0.55	0.47	0.39	0.38	0.43	0.54	0.48	Middle Income
SP	0.56	0.54	0.50	0.42	0.48	0.47	0.48	0.49	High Income
TO	0.56	0.58	0.50	0.45	0.49	0.49	0.52	0.51	Middle Income
Mean by occupation	0.56	0.56	0.49	0.43	0.47	0.46	0.52		

Source: Search results. Acre (AC), Alagoas (AL), Amapá (AP), Amazonas (AM), Bahia (BA), Ceará (CE), Distrito Federal(DF), Espírito Santo (ES), Goiás (GO), Maranhão (MA), Mato Grosso (MT), Mato Grosso do Sul (MS), Minas Gerais (MG), Pará (PA), Paraíba (PB), Paraná (PR), Pernambuco (PE), Piauí (PI), Rio de Janeiro (RJ), Rio Grande do Norte (RN), Rio Grande do Sul (RS), Rondônia (RO), Roraima (RR), Santa Catarina (SC), São Paulo (SP), Sergipe (SE), Tocantins (TO).

Table B.6 – Education market frictions τ^{h}_{ir} - 2015

State	Managers	Sciences and arts	Middle-level technicians	Service sector	Agriculture	Industrial production and services	Teachers	**Mean friction by state**	Income Level
AC	0	0.09	1.83	−0.70	1.72	−0.35	−0.72	0.27	Middle Income
AL	0	−0.52	−0.12	−0.77	0.92	−0.48	−0.69	−0.24	Low Income
AM	0	−0.22	0.21	−0.55	9.96	−0.30	−0.47	1.23	Middle Income
AP	0	0.14	0.43	−0.67	11.87	−0.18	−0.70	1.56	Middle Income
BA	0	−0.46	0.29	−0.69	7.44	−0.34	−0.45	0.83	Low Income
CE	0	−0.25	0.32	−0.68	33.70	−0.29	−0.46	4.62	Low Income
DF	0	−0.62	−0.10	−0.60	170.40	0.95	−0.43	24.23	High Income
ES	0	−0.42	0.34	−0.35	4.88	−0.31	0.12	0.61	High Income
GO	0	−0.16	0.36	−0.68	3.88	−0.48	−0.26	0.38	Middle Income
MA	0	−0.03	0.59	−0.57	4.48	−0.15	−0.60	0.53	Low Income
MG	0	−0.51	0.44	−0.49	6.16	−0.24	−0.16	0.74	Middle Income
MS	0	−0.32	1.11	−0.45	2.91	−0.15	−0.26	0.41	High Income
MT	0	−0.38	0.70	−0.59	0.62	−0.53	−0.27	−0.06	High Income
PA	0	−0.27	0.12	−0.77	1.93	−0.47	−0.62	−0.01	Low Income
PB	0	−0.57	0.19	−0.62	6.90	−0.19	−0.60	0.73	Low Income
PE	0	−0.43	0.56	−0.54	26.38	0.13	−0.09	3.72	Low Income
PI	0	0.17	1.17	−0.56	9.07	−0.28	−0.54	1.29	Low Income
PR	0	−0.25	0.58	−0.31	9.78	−0.05	0.11	1.41	High Income
RJ	0	−0.76	0.03	−0.70	129.70	−0.34	−0.33	18.23	High Income
RN	0	−0.24	0.51	−0.52	20.34	0.30	−0.27	2.88	Low Income
RO	0	0.10	0.79	−0.54	1.11	−0.49	−0.22	0.11	Middle Income
RR	0	0.17	0.22	−0.52	8.05	−0.04	−0.75	1.02	Middle Income
RS	0	−0.55	0.20	−0.53	11.59	−0.17	0.01	1.51	High Income
SC	0	−0.13	0.79	−0.32	6.14	−0.21	0.43	0.96	High Income
SE	0	−0.36	0.36	−0.71	3.96	−0.32	−0.63	0.33	Middle Income
SP	0	−0.49	0.46	−0.39	51.65	0.08	0.61	7.42	High Income
TO	0	−0.29	0.79	−0.54	0.93	−0.27	−0.60	0.00	Middle Income
Mean by occupation	0	−0.28	0.49	−0.57	20.24	−0.19	−0.33		

Source: Search results.

Table B.7 – Total productivity factors - 2015

State	A_r	State	A_r	State	A_r
AC	24.68	MA	26.59	RJ	38.49
AL	26.75	MG	41.38	RN	34.65
AM	30.76	MS	40.28	RO	38.19
AP	25	MT	39.83	RR	24.22
BA	33.07	PA	29.81	RS	45.89
CE	30.61	PB	28.79	SC	49.75
DF	35.99	PE	39.56	SE	30.90
ES	46.65	PI	27.93	SP	51.25
GO	40.42	PR	46.44	TO	28.03

Source: Search results.

Notes: Recall that in our model TFP is equal across occupations. The average of TFP is 35.4.

Table B.8 – Labor market frictions τ_{ir}^{w} - 2003

State	Managers	Sciences and arts	Middle-level technicians	Service sector	Agriculture	Industrial production and services	Teachers	**Mean friction by state**	Income Level
AC	−0.05	−0.06	−0.28	−0.72	−0.98	−0.68	−0.36	−0.45	Middle Income
AL	−0.05	0.10	−0.34	−0.76	−0.94	−0.50	−0.38	−0.41	Low Income
AM	−0.05	−0.12	−0.65	−0.82	−0.92	−0.75	−0.47	−0.54	Middle Income
AP	−0.05	−0.15	−0.36	−0.68	−0.74	−0.45	−0.31	−0.39	Middle Income
BA	−0.05	−0.08	−0.22	−0.69	−0.77	−0.54	−0.42	−0.40	Low Income
CE	−0.05	−0.06	−0.22	−0.67	−1.00	−0.68	−0.38	−0.44	Low Income
DF	−0.05	−0.02	−0.16	−0.50	−0.22	−0.45	−0.16	−0.22	High Income
ES	−0.05	−0.15	−0.19	−0.58	−0.53	−0.50	−0.28	−0.33	High Income
GO	−0.05	−0.05	−0.15	−0.57	−0.38	−0.48	−0.30	−0.28	Middle Income
MA	−0.05	−0.01	−0.39	−0.63	−0.61	−0.54	−0.28	−0.36	Low Income
MG	−0.05	−0.06	−0.20	−0.61	−0.58	−0.45	−0.20	−0.31	Middle Income
MS	−0.05	0.02	−0.18	−0.50	−0.14	−0.52	−0.28	−0.24	High Income
MT	−0.05	−0.06	−0.30	−0.64	−0.41	−0.47	−0.36	−0.33	High Income
PA	−0.05	−0.02	−0.25	−0.64	−0.38	−0.54	−0.25	−0.30	Low Income
PB	−0.05	−0.06	−0.25	−0.74	−0.87	−0.76	−0.34	−0.44	Low Income
PE	−0.05	−0.07	−0.29	−0.67	−0.93	−0.64	−0.41	−0.44	Low Income
PI	−0.05	0.02	−0.39	−0.74	−1.00	−0.93	−0.50	−0.51	Low Income
PR	−0.05	−0.10	−0.21	−0.54	−0.29	−0.41	−0.22	−0.26	High Income
RJ	−0.05	−0.04	−0.19	−0.53	−0.92	−0.38	−0.13	−0.32	High Income
RN	−0.05	0.01	−0.22	−0.61	−1.00	−0.53	−0.23	−0.38	Low Income
RO	−0.05	0.01	−0.15	−0.58	−0.18	−0.40	−0.16	−0.22	Middle Income
RR	−0.05	−0.18	−0.27	−0.60	−0.61	−0.61	−0.29	−0.37	Middle Income
RS	−0.05	−0.04	−0.18	−0.50	−0.34	−0.44	−0.19	−0.25	High Income
SC	−0.05	−0.05	−0.10	−0.36	−0.14	−0.31	−0.19	−0.17	High Income
SE	−0.05	0.04	−0.27	−0.61	−0.78	−0.57	−0.41	−0.38	Middle Income
SP	−0.05	−0.11	−0.19	−0.49	−0.45	−0.39	−0.25	−0.28	High Income
TO	−0.05	0.01	−0.18	−0.72	−0.56	−0.46	−0.38	−0.34	Middle Income
Mean by occupation	−0.05	−0.05	−0.25	−0.62	−0.62	−0.53	−0.30		

Source: Search results.

Table B.9 – Education market frictions τ_{ir}^{h} - 2003

State	Managers	Sciences and arts	Middle-level technicians	Service sector	Agriculture	Industrial production and services	Teachers	**Mean friction by state**	Income Level
AC	0	0.49	2.93	0.23	155.73	3.97	0.03	23.34	Middle Income
AL	0	−0.19	1.75	0.73	14.16	1.50	−0.15	2.54	Low Income
AM	0	0.71	3.83	0.24	205.14	1.32	0.80	30.29	Middle Income
AP	0	−0.00	0.49	−0.15	77.86	−0.16	−0.68	11.05	Middle Income
BA	0	0.33	1.24	0.34	16.33	1.66	0.86	2.97	Low Income
CE	0	−0.11	0.82	−0.17	51.68	0.99	0.13	7.62	Low Income
DF	0	−0.58	0.32	−0.02	253.03	3.08	−0.20	36.52	High Income
ES	0	0.37	1.60	0.46	12.16	1.39	0.92	2.41	High Income
GO	0	0.27	1.01	0.19	10.03	1.01	1.14	1.95	Middle Income
MA	0	−0.06	2.00	−0.05	5.79	0.68	−0.40	1.14	Low Income
MG	0	0.05	1.46	0.39	23.15	0.93	0.26	3.75	Middle Income
MS	0	0.78	3.69	0.35	7.17	2.07	1.26	2.19	High Income
MT	0	0.31	3.40	1.29	5.16	1.41	1.18	1.82	High Income
PA	0	−0.34	0.82	−0.26	28.28	0.52	0.03	4.15	Low Income
PB	0	0.38	1.39	0.56	28.44	3.18	−0.16	4.83	Low Income
PE	0	−0.19	0.93	0.00	54.79	2.18	0.45	8.31	Low Income
PI	0	−0.13	1.17	0.29	27.12	5.69	−0.22	4.84	Low Income
PR	0	0.21	1.20	0.55	14.87	1.27	0.83	2.70	High Income
RJ	0	−0.63	0.28	−0.33	360.08	0.31	−0.18	51.36	High Income
RN	0	−0.45	1.66	−0.32	28.81	0.43	−0.55	4.23	Low Income
RO	0	1.20	1.11	0.00	7.43	0.29	−0.28	1.39	Middle Income
RR	0	0.13	4.32	0.38	50.15	3.63	−0.41	8.32	Middle Income
RS	0	−0.08	0.86	0.39	21.53	1.06	0.78	3.51	High Income
SC	0	0.78	1.27	0.56	8.81	0.76	1.24	1.92	High Income
SE	0	−0.19	1.01	−0.13	16.92	0.81	−0.21	2.60	Middle Income
SP	0	−0.24	1.11	0.20	81.56	1.02	1.25	12.13	High Income
TO	0	0.30	1.87	1.62	13.17	2.16	0.37	2.79	Middle Income
Mean by occupation	0	0.12	1.61	0.27	58.49	1.60	0.30		

Source: Search results.

Table B.10 – Total productivity factors - 2003

State	A_r	State	A_r	State	A_r
AC	25	MA	19.65	RJ	28.93
AL	20.95	MG	31.16	RN	18.05
AM	31.24	MS	36.08	RO	24.47
AP	15.60	MT	34.85	RR	19.02
BA	30.05	PA	27.16	RS	37.54
CE	24.95	PB	21.09	SC	39.91
DF	26.92	PE	26.77	SE	19.57
ES	35.74	PI	17.88	SP	40.71
GO	36.73	PR	36.03	TO	25.16

Source: Search results.
Notes: Recall that in our model TFP is equal across occupations. The average of TFP is 27.82.

B.3 Public and Private Spending on Education

We estimated private education expenditures in Brazil for 2003, 2009, and 2018 using data from Table 49 of the Family Budget Survey (POF).[1] Our estimates indicate that private education expenditures were approximately R$ 32.4 billion in 2003, R$ 40.5

[1] Details about the POF can be found on the Brazilian Institute of Geography and Statistics (IBGE) website: https://www.ibge.gov.br/.

billion in 2009, and R$ 145.4 billion in 2018. The private education expenditures as a percentage of GDP were 1.8%, 1.2%, and 2.0% for the respective years, with an average of 1.7%.

The National Institute of Educational Studies and Research Anísio Teixeira (INEP) provides data on public spending on education as a percentage of GDP. In 2003, public spending on education accounted for 4.6% of GDP, while in 2015, it increased to 6.2%. Therefore, Brazil's total public and private spending on education, as a share of GDP, was 6.4% in 2003 and 7.9% in 2015.

B.4 Migration Between States

We analyzed the PNAD microdata from 2015 to assess the extent of worker migration, finding that, on average, 20.36% of workers moved to another state or country. Table B.11 presents the proportion of workers who relocated to another state or country by occupation. As illustrated, only a small proportion of employees relocated from their home state to another. Thus, assuming that workers do not migrate in the theoretical model is reasonable.

Table B.11 – Share of workers who migrated and did not migrate to another state or country

	Managers	Sciences and arts	Middle-level technicians	Service sector	Agriculture	Industrial production and services	Teachers
Migrated	0.21	0.18	0.19	0.22	0.20	0.22	0.15
Not Migrated	0.79	0.82	0.81	0.78	0.80	0.78	0.85

Source: Elaborated by the authors with data from PNAD 2015.

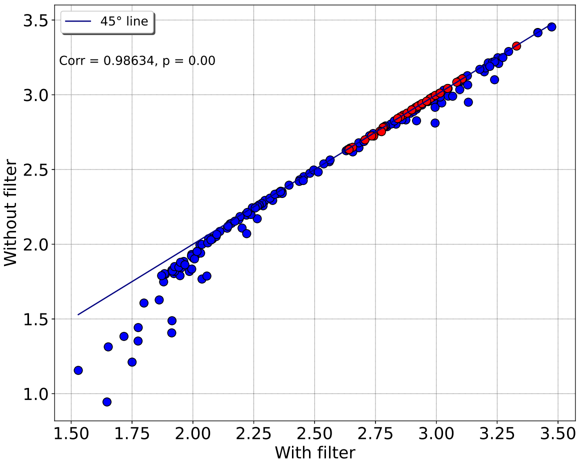
B.5 Alternative Calibration

There are many microeconomic issues in Brazil, and informal work is an important one. Scholars have conducted extensive research to understand the relationship between economic development and the informal sector. For instance, Franjo, Pouokam and Turino (2022) built a life-cycle model to explore the interplay between informality and financial development in Brazil. They also conducted cross-country data analysis, highlighting the importance of considering the informal sector when studying the relationship between financial and economic development.

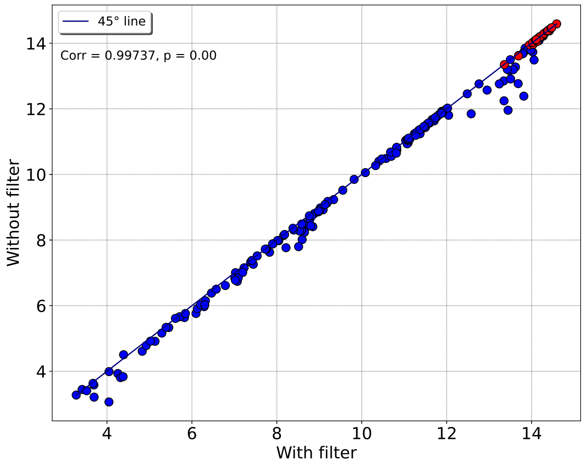
The prevalence of informal employment is not unique to Brazil; it is a common feature in many developing countries. Research conducted by Bacchetta et al. (2009) reveals that informality negatively correlates with GDP and GDP growth in developing countries. During the 2000s, the proportion of informal employment in total employment was 52% for Latin America, 78% for Asia, and 56% for Africa. The informal sector (excluding agriculture) accounted for 26% of Latin America's GDP in 2006. Moreover, the research suggests that informal employment tends to attract low-educated workers, with approximately 65% of all informal workers in Latin America classified as such.

The decision to exclude individuals earning less than 60% of the minimum wage could raise concerns as it may disproportionately impact workers in the informal sector. To address this concern and ensure the robustness of our findings, we provide an alternative calibration of our model that incorporates data from all workers with positive wages. Our primary analysis focused on a sample of 109,038 individuals after applying specific filters described in the main text. Here, we constructed a broader dataset comprising 115,994 individuals and compared the filtered (With filter) and unfiltered (Without filter) samples in terms of wages, educational attainment, and worker proportions, as shown in Figure B.1, where the red points represent teachers' statistics. We observed minor differences between the two samples for teaching professions, with the most significant disparities occurring in low-wage occupations, such as those in the agricultural sector.

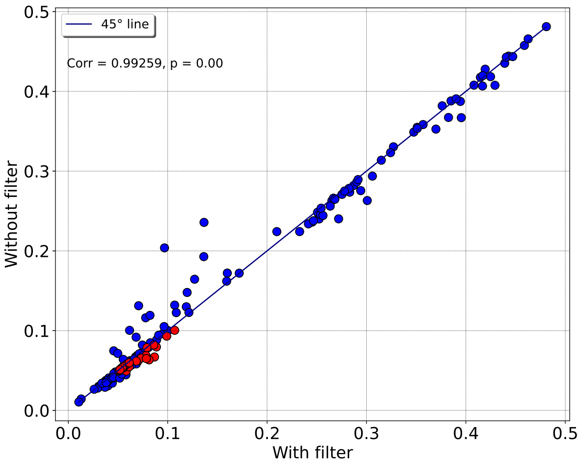
Figure B.1 – Data – Sample with wages filter vs. sample without wages filter



(a) Wages



(b) Years of schooling



(c) Proportion of workers

Notes: This figure compares our main calibration data (With filter) and the data without wage filters (Without filter). In the figure, the red dots represent observations of teachers, while the blue dots denote other occupations.

We recalibrated our model using the extended sample. Figure B.2 demonstrates that the alternative calibration effectively fits the data. We also compared the calibrated parameters from the main text to those computed with the extended sample, as shown in Figure B.3. The parameters linked to teachers' occupations (marked in red) showed no substantial alterations. Moreover, the TPF (A_i) and educational market barriers (τ_h) are almost indistinguishable in both calibrations. While there are some differences in labor market barriers (τ_w), a high correlation is observed between the alternative calibration of these parameters.

Figure B.2 – Model adjustment to data with full sample- wages and share of workers

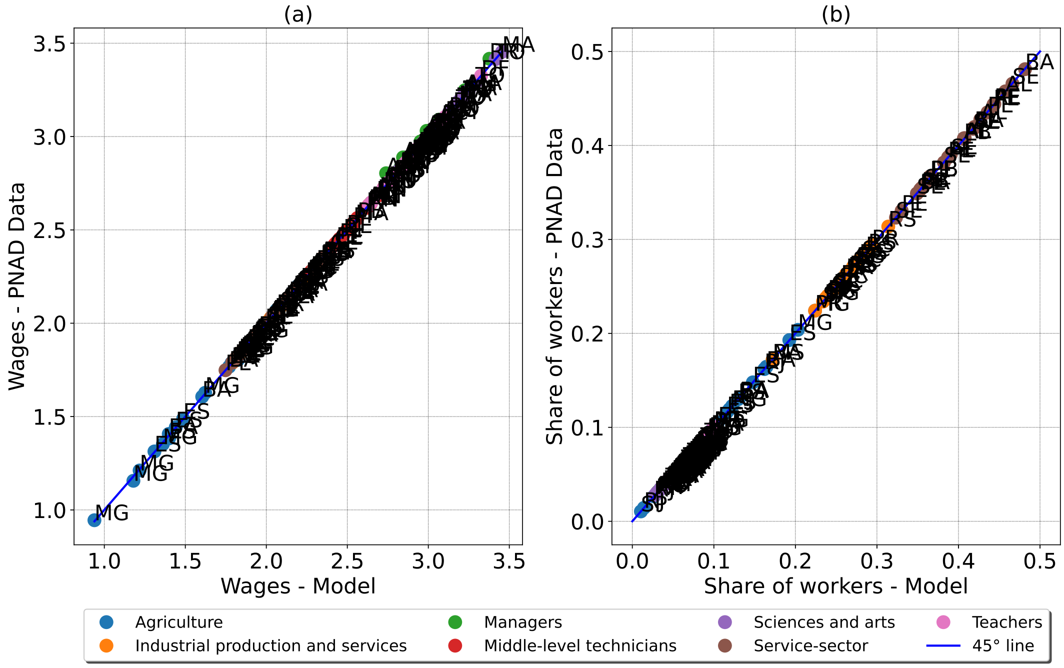
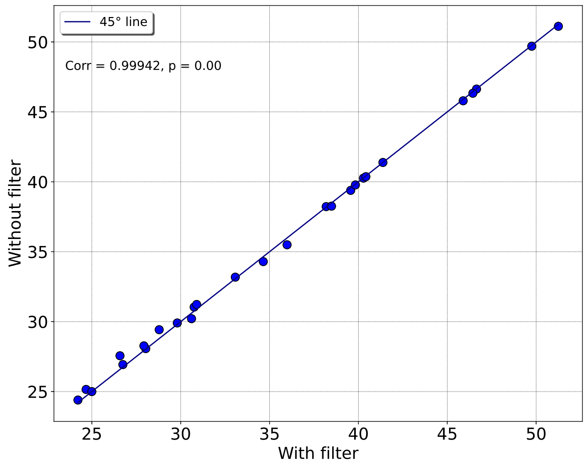
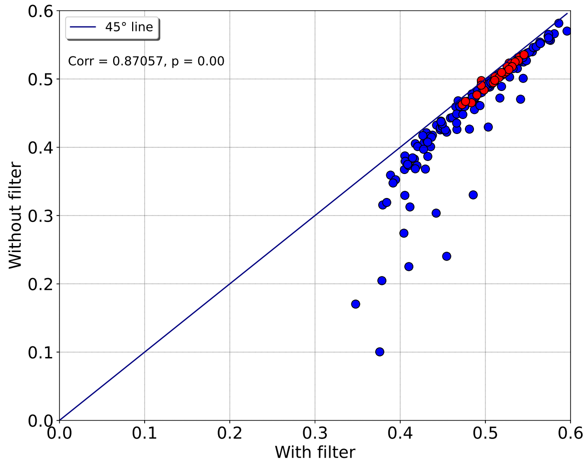


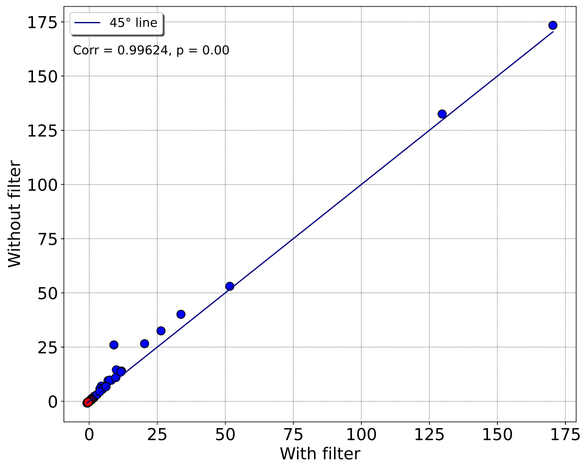
Figure B.3 – Calibrated parameters – Sample with wages filter vs. sample without wages filter



(a) TFP (A_i)



(b) τ_w



(c) τ_h

Notes: This figure compares the calibrated parameters obtained from the original calibration (with filter) to those obtained from the calibration without wage filters (without filter).

We have verified that many important results from our analysis remain robust when using the alternative calibration. Table B.12 presents the outcomes of counterfactual experiments using both the primary and alternative calibrations. In the first scenario, we assumed that all states have the same frictions (τ_w's and τ_h's) as Roraima (RR), the state with the highest Average Teachers' Human Capital (ATHC). Using the alternative calibration, we find that the Brazilian GDP would increase by 87.51% (compared to 87.85% in our primary exercise).

Suppose all states had the same frictions as São Paulo (SP), the state with the lowest ATHC. In that case, we find that the GDP of all states would decrease, and the

Brazilian GDP would decline by 53.74% according to the alternative calibration (compared to 59.62% in our primary calibration).

Finally, in the exercise where we eliminate all frictions in the economy, the alternative calibration suggests that the GDP could increase by 18.3% (compared to 16.94% predicted by the same exercise using our primary calibration).

Therefore, the results in Table B.12 show that the main findings are not significantly affected by the different calibration choices, indicating that our model's results are not sensitive to excluding individuals earning less than 60% of the minimum wage.

Table B.12 – Main counterfactual exercises – Sample with wages filter (Original calibration) vs. sample without wages filter

	Main Counterfactuals (%)	
	Main calibration	Alternative calibration
Highest ATHC	87.85	87.51
Lowest ATHC	-59.62	-53.74
Without frictions	16.94	18.30

Notes: This table compares the main counterfactuals of the main calibration of our model to the counterfactuals computed using the extended sample.

B.6 Teachers' Relative Wages and Economic Development

In this section, to further investigate the link between economic development and the relative earnings of teachers, we conducted a panel regression analysis using all available data from the household survey (PNAD) covering the period from 2002 to 2015 (excluding 2010 due to lack of data). Our analysis includes information on the average wage of teachers relative to other occupations, the proportion of teachers in public institutions, and the ratio of teachers with labor municipality contracts to teachers with state contracts for all years and states.

The structure of the Brazilian education system differs from that of other economies. The Organization for Economic Cooperation and Development (OECD) notes that funding for different levels of education in Brazil is divided among the municipality, state, and federal governments. Typically, the municipal government provides funding for the lowest level of education, the state government funds the intermediate level, and the federal government funds higher education, such as colleges and universities. Moreover, the proportion of teachers financed by each administrative level also varies. In 2015, across the Brazilian states, the average percentages of teachers in public institutions were 55%, 39%, and 6% for the municipal, state, and federal levels, respectively. The standard deviations for these percentages were 16%, 15%, and 3%, respectively.

These numbers suggest significant variations in the distribution of teachers across administrative levels and regions. As teachers in different states or municipalities within the same state may receive different salaries, we consider the proportion of teachers in public institutions and the ratio of teachers with labor municipality contracts to teachers with state contracts in our analysis.

The dependent variable in our panel regression is the relative wage of teachers to other occupations. We explore whether the proportion of public teachers can account for the observed differences in relative wages, controlling for time and state-fixed effects. The first model (Model 1) examines this relationship. The second model (Model 2) expands on the first by adding the ratio of municipality teachers to state teachers. Finally, the third model (Model 3) further extends the analysis by including the log of GDP per capita as an additional regressor.

The regression results presented in Table B.13 indicate that neither the proportion of teachers in public institutions nor the ratio of municipality teachers to state teachers significantly impact the relative wages of teachers. However, we do find a negative correlation between GDP per capita and relative wages, which is consistent with our earlier findings.

Table B.13 – The effect of teachers from public institutions on relative wages of teachers

	(1)	(2)	(3)
Share of pub. teachers	-0.21	-0.21	-0.14
	(0.27)	(0.27)	(0.26)
Municipality to state pub. teachers		0.001	-0.004
		(0.02)	(0.021)
GDP per capita			-0.04***
			(0.01)
Constant	✓	✓	✓
Time Fixed Effect	✓	✓	✓
State Fixed Effect	✓	✓	✓
Observations	351	351	351

Note: We report robust t-statistics in parentheses. Statistical significance is indicated at the $***p < 0.01$, $**p < 0.05$, and $*p < 0.1$ levels. Our dataset comprises all household surveys conducted after 2000 with a consistent methodology (2002-2009, 2011-2015). We compute the weighted average of the relative wage of teachers to other occupations and the proportion of teachers in public institutions for all years and states. Our sample includes individuals aged 25 to 65 with positive wages, yielding 351 observations (13 years multiplied by 27 states). Our panel regression analysis consists of three models. In Model 1, we examine whether the proportion of public teachers explain differences in relative wages, controlling for time and state-fixed effects. Model 2 introduces the ratio of municipal to state-funded teachers across states. Finally, in Model 3, we extend the analysis by including the log of GDP per capita in the second model.

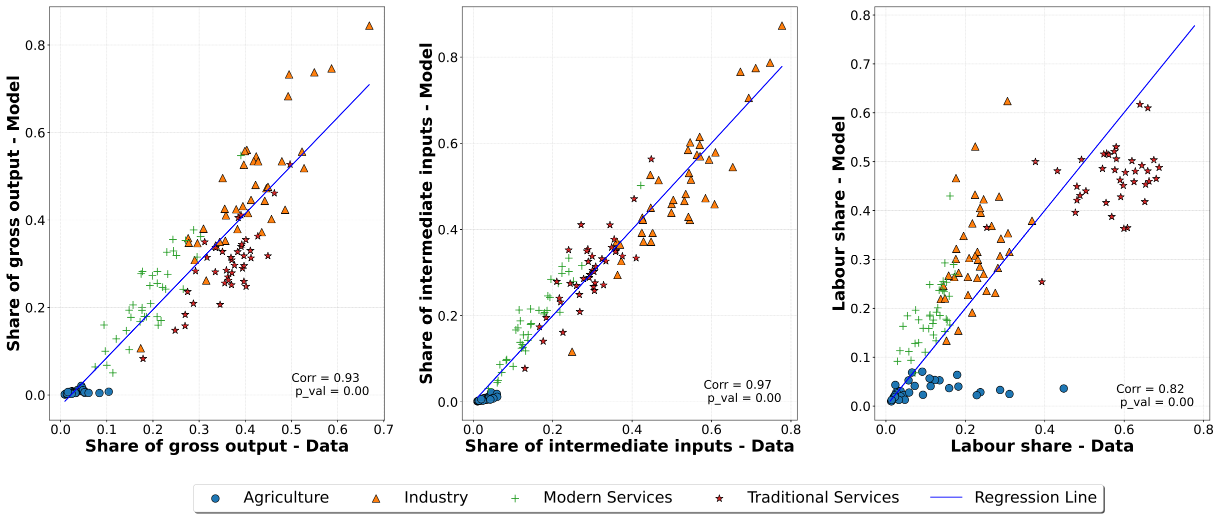
APPENDIX C – From Chapter 4

C.1 Model Results

Table C.1: Sectoral Productivity

Country	Code	Agriculture	Industry	Modern Services	Traditional Services
Australia	AUS	0.57	1.61	1.97	0.71
Austria	AUT	0.16	1.59	1.64	0.78
Belgium	BEL	0.28	1.80	1.80	0.84
Brazil	BRA	0.14	1.41	1.89	0.45
Bulgaria	BGR	0.08	1.67	1.92	0.80
Canada	CAN	0.53	1.70	1.74	0.75
China	CHN	0.22	1.14	1.15	0.30
Cyprus	CYP	0.29	1.25	1.74	0.85
Czech Republic	CZE	0.47	1.85	2.11	1.12
Denmark	DNK	0.42	1.74	1.74	0.81
Estonia	EST	0.52	1.70	1.66	1.09
Finland	FIN	0.26	1.61	1.76	0.72
France	FRA	0.39	1.51	1.64	0.66
Germany	DEU	0.16	1.38	1.63	0.65
Greece	GRC	0.36	1.84	1.90	0.88
Hungary	HUN	0.53	1.99	1.63	0.93
India	IND	0.27	1.01	0.79	0.31
Indonesia	IDN	0.15	1.40	1.24	0.30
Ireland	IRL	0.29	2.10	2.00	0.95
Italy	ITA	0.26	1.48	1.75	0.79
Japan	JPN	0.17	1.36	1.41	0.77
Latvia	LVA	0.53	1.62	1.80	1.09
Lithuania	LTU	0.25	1.93	1.43	1.00
Mexico	MEX	0.20	1.80	1.68	1.30
Netherlands	NLD	0.51	1.95	1.58	0.79
Norway	NOR	1.12	2.23	1.78	0.94
Poland	POL	0.21	1.86	1.87	1.10
Portugal	PRT	0.08	1.54	1.96	0.77
Republic of Korea	KOR	0.10	1.59	1.33	0.54
Romania	ROU	0.33	1.57	1.94	0.65
Russian Federation	RUS	0.13	1.51	0.97	0.59
Slovakia	SVK	0.72	1.62	1.88	1.10
Slovenia	SVN	0.10	1.35	1.29	0.70
Spain	ESP	0.28	1.71	1.68	0.68
Sweden	SWE	0.19	1.77	1.94	0.88
Switzerland	CHE	1.09	1.71	1.59	0.91
Turkey	TUR	0.28	1.34	1.38	0.57
United Kingdom	GBR	0.21	1.29	1.54	0.68
United States	USA	0.78	2.36	2.42	1.71

Figure C.1 – Comparison Between Data and Model Results



C.2 Bonacich-Katz Centrality Index

In this section, we describe how to calculate Bonacich-Katz centrality index that measure the importance of a sector as supplier to economy. According to (GRASSI; SAUVAGNAT, 2019) Bonacich-Katz centrality index can be defined by:

$$b_i = \beta_i + \sum_j b_j \Sigma_{ji}, \tag{C.1}$$

where $\beta_i = \frac{C_i+G_i+I_i+X_i}{GDP}$ is the importance of sector i as supplier to final demand, and is known as Domar Weights, and $\Sigma_{ji} = \frac{X_{ij}}{Q_i}$, where Q_i is the gross product and X_{ij} is the input output matrix.[1] This shows that the centrality of a sector is equal to the importance of that sector as a supplier to the final demand plus the weighted sum of the centrality of its customer sectors. This equation is a system with four equations with four unknowns, that is, the Bonacity-Katz centrality index for each sector. The solution of this system can be written as follows.

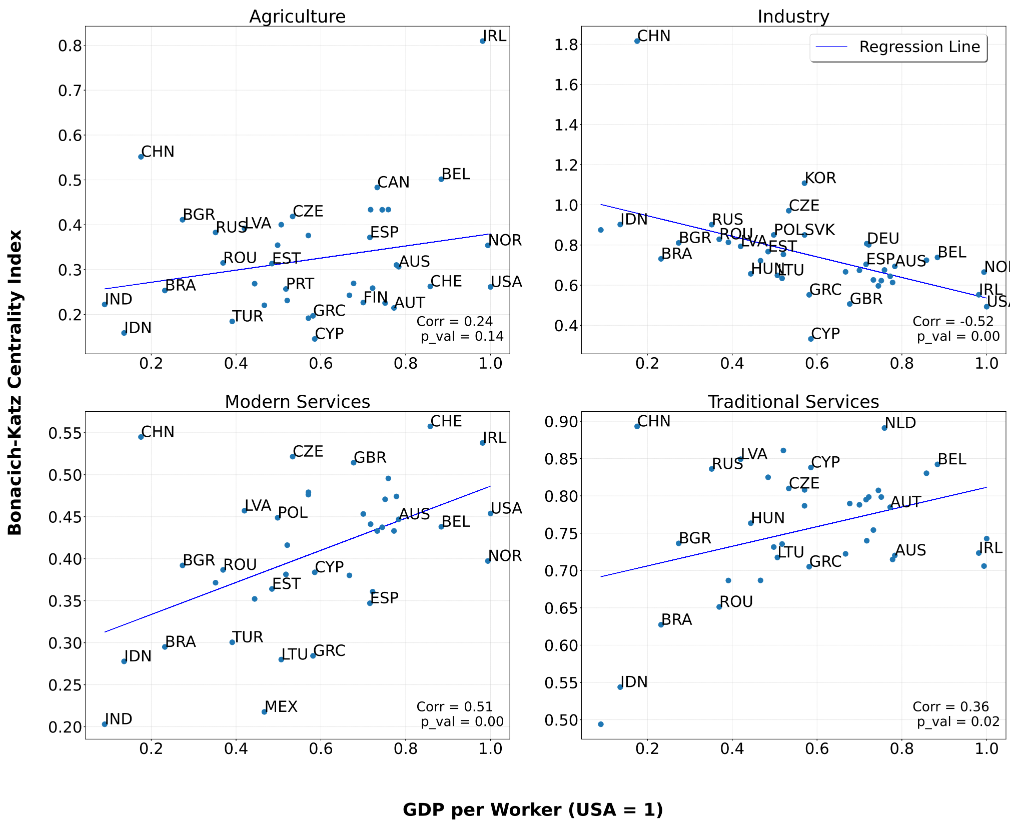
$$b' = \beta'(I-\Sigma)^{-1} = \beta' + \beta'\Sigma + \beta'\Sigma^2 + \beta'\Sigma^3 + \cdots + \beta'\Sigma^k + \cdots, \tag{C.2}$$

[1] We highlight that C_i, G_i, I_i and X_i are consumption, government spend, investments and net exports, respectively.

where b' is the centrality vector and $(I - \Sigma)^{-1}$ is the Leontief inverse matrix.

In Figure C.2 we present this measure together with GDP per worker. The Bonacich-Katz centrality index of traditional and modern services is positively associated with the countries' level of development; the correlation of the centrality index of these subsectors with GDP per capita is 0.31 and 0.54, respectively, both statistically significant at 1%. On the other hand, the industry centrality index is negatively correlated with the countries' income level, and in agriculture there is no statistically significant relationship.

Figure C.2 – Bonacich-Katz Centrality Index - 2014



C.3 Sectoral Trends

Table C.2 – Panel Regression Models, Sectoral Share of Value Added - 2000:2014

	Dependent Variable: Share of Added Value			
	(1) Agriculture	(2) Industry	(3) Modern Services	(4) Traditional Services
Ln GDP per Capita	−0.081***	−0.008	0.108***	−0.019
Ln GDP per Capita Squared	0.010***	0.010***	−0.021***	0.001
Ln Population	−0.294***	−0.950***	1.176***	0.068
Ln Population Squared	0.011***	0.027***	−0.037***	−0.0002
D05	−0.005***	−0.007***	0.008***	0.005***
D08	−0.010***	−0.013***	0.021***	0.003
D11	−0.011***	−0.032***	0.031***	0.012***
D14	−0.011***	−0.041***	0.037***	0.015***
Country Fixed Effects	✓	✓	✓	✓
Observations	585	585	585	585
R^2	0.552	0.464	0.455	0.203
Adjusted R^2	0.514	0.418	0.409	0.135
F Statistic (df = 8; 538)	83.009***	58.253***	56.172***	17.119***

Notes: Statistical significance is indicated at the $***p < 0.01$, $**p < 0.05$, and $*p < 0.1$ levels. Our dataset comprises data from 2000 to 2014. We use four time dummies variables: D05, D08, D11, and D14 that indicate whether the period goes from 2003 to 2005, 2006 to 2008, 2009 to 2011 and 2012 to 2014, respectively. Note that we exclude dummy that indicates the period goes from 2000 to 2002.

C.4 Sectoral Classification

Table C.3: Sectoral classification

Sector names	Sector group
Crop and animal production, hunting and related service activities	Agriculture
Forestry and logging	Agriculture
Fishing and aquaculture	Agriculture
Mining and quarrying	Industry
Manufacture of food products, beverages and tobacco products	Industry
Manufacture of textiles, wearing apparel and leather products	Industry
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Industry
Manufacture of paper and paper products	Industry
Printing and reproduction of recorded media	Industry
Manufacture of coke and refined petroleum products	Industry
Manufacture of chemicals and chemical products	Industry
Manufacture of basic pharmaceutical products and pharmaceutical preparations	Industry

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Table C.3: Sectoral classification (Continued)

Sector names	Sector group
Manufacture of rubber and plastic products	Industry
Manufacture of other non-metallic mineral products	Industry
Manufacture of basic metals	Industry
Manufacture of fabricated metal products, except machinery and equipment	Industry
Manufacture of computer, electronic and optical products	Industry
Manufacture of electrical equipment	Industry
Manufacture of machinery and equipment n.e.c.	Industry
Manufacture of motor vehicles, trailers and semi-trailers	Industry
Manufacture of other transport equipment	Industry
Manufacture of furniture; other manufacturing	Industry
Repair and installation of machinery and equipment	Industry
Electricity, gas, steam and air conditioning supply	Industry
Water collection, treatment and supply	Industry
Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	Industry
Construction	Industry
Wholesale and retail trade and repair of motor vehicles and motorcycles	Traditional Services
Wholesale trade, except of motor vehicles and motorcycles	Traditional Services
Retail trade, except of motor vehicles and motorcycles	Traditional Services
Land transport and transport via pipelines	Traditional Services
Water transport	Traditional Services
Air transport	Modern Services
Warehousing and support activities for transportation	Traditional Services
Postal and courier activities	Traditional Services
Accommodation and food service activities	Traditional Services
Publishing activities	Modern Services
Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities	Modern Services
Telecommunications	Modern Services
Computer programming, consultancy and related activities; information service activities	Modern Services
Financial service activities, except insurance and pension funding	Modern Services
Insurance, reinsurance and pension funding, except compulsory social security	Modern Services
Activities auxiliary to financial services and insurance activities	Modern Services
Real estate activities	Modern Services
Legal and accounting activities; activities of head offices; management consultancy activities	Modern Services
Architectural and engineering activities; technical testing and analysis	Modern Services
Scientific research and development	Modern Services
Advertising and market research	Modern Services
Other professional, scientific and technical activities; veterinary activities	Modern Services
Administrative and support service activities	Traditional Services
Public administration and defence; compulsory social security	Traditional Services
Education	Traditional Services
Human health and social work activities	Traditional Services
Other service activities	Traditional Services

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Table C.3: Sectoral classification (Continued)

Sector names	Sector group
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	Traditional Services
Activities of extraterritorial organizations and bodies	Traditional Services

Notes： Adapted from World Input-Output Database.