Multinationals' Entry: Boon or Bane for Non-Frontier Economies?*

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Abstract

Most countries in the world are not at the technological frontier, yet their economies grow and fluctuate. In this paper we set up a quantitative model of endogenous growth with business cycle fluctuations usable to analyze the medium frequency fluctuations in non-frontier countries. The growth mechanism is a Schumpeterian creative destruction framework, which is embedded into a real business cycle dynamic stochastic general equilibrium model, with standard and non-standard features. We allow for multinational firms entering the economy and challenging existing incumbents, and study the tension between their direct positive productivity contribution and their indirect negative contribution through the expected obsolescence of domestic innovators. We estimate the model using a full-information approach and show that multinationals' entry is both boon and bane for non-frontier economies.

JEL classification: E2, E3, F2, F4, O3, O4

Keywords: DSGE; Schumpeterian Growth; Medium Frequencies; Capital Inflows; Non-frontier Economies; Multinational Corporations.

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1 Introduction

Non-frontier open economies, by their nature, are always exposed to Schumpeterian competition of foreign origins, i.e. firms operating in frontier economies, usually characterized by better knowledge of frontier technologies.[1] This is a point emphasized by a convincing empirical literature on the causes and effects of foreign direct investment (FDI) of multinational companies (MNCs) on the destination economies. In terms of triggers, a vast empirical literature (e.g. Calvo et al. (1996), Kim (2000), De Vita and Kyaw (2008), Forbes and Warnock (2012), Ahmed and Zlate (2014) and Ghosh et al. (2014), among others) shows that global factors, more than domestic developments, are to be accounted for the international capital flows to developing countries (DCs) or emerging markets (EMs). Regarding the positive effects of FDI for the destination country, Calvo et al. (1996) point to the economic growth enhancement and welfare improvement, achieved through increased consumption and investment.[2] However, the authors document the fact that large capital inflows have also many drawbacks. The procyclicality of foreign investments, in particular, has received great attention from scholars and policy-makers alike, because it may expose destination countries to abrupt reversals, capital inflows booms and busts being often linked to the business cycles in these countries.[3]

In this paper we address the question whether MNCs' entry is boon or bane for non-frontier economies. The macroeconomics literature so far quarantines off one aspect of MNCs' entry at a time, business cycles effects being studied in isolation from those related to trend growth. However, the need to understand the consequences of MNCs' entry calls for a more integrated approach. To this end, we set up the first macroeconomic model able to account for the role played by MNCs' entry in driving economic fluctuations at high and low frequencies in a non-frontier small open economy (SOE).

We develop a dynamic stochastic general equilibrium (DSGE) model with endogenous adoption of an exogenously evolving technological frontier developed abroad. Domestic firms invest in research and development (R&D) in order to reduce the gap between their sector's productivity and the technological frontier, hoping to appropriate the associated profits by establishing intellectual property rights (IPRs) on it. They will be challenged by future domestic innovators, which leads to business dynamics typical of the Schumpeterian creative destruction literature stemming from Aghion and Howitt (1992). The mechanism of entry of better firms and exit of technologically obsolete firms emphasized by this literature (recently culminating in the works of Acemoglu et al., 2018) captures the importance of resource reallocation as an engine of growth that is instead missed in models of horizontal innovations, stemming from Romer (1990) and culminating with Comin and Gertler (2006), which unrealistically predict that firm exit is always bad for growth.

[1]Broadly intended, inclusive not only of purely engineering blueprints, but also of better management practices, and whatever renders them more productive than local firms.

[2]Many empirical studies find supporting evidence in favor of the fact that FDI is growth-enhancing. For details, see Mello (1999), Alfaro et al. 2004; 2010, Adams and Opoku (2015), and Javorcik (2015), among others.

[3]See, e.g., Kaminsky et al. (2004), Reinhart and Reinhart (2009), Blanchard et al. (2010), Broner et al. (2013), Milesi-Ferretti and Tille (2014), Benigno et al. (2015), Araujo et al. (2017a), for empirical work on the linkages between capital inflows and the domestic business cycle.

While theoretical models without an explicit Schumpeterian creative destruction focus are biased in favor of positive effects of MNCs' entry, our creative destruction mechanism allows for more flexibility, as effects could overall be positive or negative, and depending on the data used in a calibrated or estimated version of our model, predictions may change. In fact, here we allow for a probability of entry of foreign MNCs transferring the foreign frontier productivity into the sector of the domestic economy in which they enter, but while this technological transfer from abroad is beneficial for the domestic economy's average productivity, it also comes at the expenses of the domestic firms in the sector, which are competed away by the entering MNC. Moreover, this reallocation effect is an additional source of creative destruction penalizing domestic innovators, which have undertaken the R&D investment targeting a partial catch-up with the world technological frontier, and then finding themselves overcome by a top quality foreign firm entering the sector. Hence, we are able to study also how the expectation of a probability of becoming obsolete by potential foreign entry affects the domestic innovator's R&D choice in the first place. While this has been studied in Schumpeterian growth models, such as Chu et al. (2014) and Cozzi and Impullitti (2016), it has never been cast in a medium frequency framework. Our DSGE model therefore has this novel feature of allowing foreign entry probability fluctuations - which may result from foreign business cycles, but also from domestic and foreign policy changes - to be a source of fluctuations of the domestic economy.

Our model has a stronger foundation in economic theory than the purely econometric models that are predominant in the literature since, by allowing for inter-dependencies between different sectors, agents and markets in the economy, it can help shed light on whether and to what extend MNCs' entry and R&D are sources of economic fluctuations in non-frontier economies. We estimate the model following a full-information approach and using real data for Hungary to quantify the relative contribution of various shocks in explaining output growth in Hungary. The choice of Hungary is motivated by the fact that the central- and south-eastern European countries which are members of the European Union (EU), henceforth the CSEE,[4] are a good example of non-frontier economies that have experienced strong economic growth and productivity gains accompanied by large FDI inflows but in the absence of considerable improvement in domestic innovation. Among them, Hungary is the country with the largest share of MNCs in the business sector in terms of value added, production, and turnover.[5]

Our estimation results, first interpreted through the impulse responses to various shocks introduced in this model, indicate that temporary shocks can cast a long shadow on the economy through both direct and indirect effects on the various model variables. In particular, stronger MNCs' entry, while discouraging domestic innovation, brings about an overall growth process in the country lasting far longer than the initial shock.

The estimation further suggests that, from a historical perspective, MNCs' entry shocks played an important role in driving the Hungarian GDP growth, especially before the Great Recession. After the accession to the EU of most CSEE countries, including Hungary, in 2004 the MNCs' entry shocks contributed the most to Hungary's GDP growth (up to 1

[4]The eleven CSEE countries which are members of the EU are Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovak Republic, and Slovenia.

[5]For details see Section 2.

percentage point in 2006Q1), acting as a catalyst of economic boom. However, from the onset of the financial crisis in 2007, we observe the drawback of the openness to foreign investment through the exposure to international shocks, MNCs' entry having an immediate negative impact on Hungarian GDP growth. According to the model estimation, negative MNCs' entry shocks depressed output growth by as much as 2.2 percentage points in 2009Q1, which amplified the economic downturn in Hungary.

An important result of this analysis is the procyclicality of capital inflows in Hungary, which is in line with the findings of various empirical studies. We perform a counterfactual exercise and find that, in the absence of MNCs' entry shocks, economic fluctuations in Hungary would have been of lower magnitude over the period 1995Q2:2019Q4. Our estimates indicate that MNCs' entry shocks not only make output more volatile but they have also dampened the recovery following both the global financial crisis and the sovereign debt crisis. The difference between the actual and the counterfactual series is most striking in the case of the financial crisis where we observe that, without the negative contribution of MNCs' entry shocks, output growth would have entered positive territory already in 2009Q2, while in reality this happened one year later.

Thus, we can conclude that MNC's entry proved to be both boon and bane for an EM such as Hungary since on the one hand it impacted positively economic growth, while on the other hand it was a significant source of business cycle amplification. On what concerns the government subsidies, the R&D subsidy shock had almost no effect on the observed variables, which highlights the insignificant role played by this shock in driving domestic productivity or output growth in both the short and medium run.

The paper is organized as follows. We first discuss the related literature. Section 2 then provides some motivating facts; Section 3 introduces the main model; Section 4 describes the calibration and estimation of the model, while Section 5 discusses the most important dynamic simulations; Section 6 concludes.

Related Literature

Our paper is related to several strands of literature. First, the paper develops on the novel literature stemming from Comin and Gertler (2006) in which productivity growth is endogenized in a DSGE framework. Successful models have recently been emerging, such as for example Roeger et al. (2008), Nuño (2011), Guerrón-Quintana and Jinnai (2014), Kung and Schmid (2015), Benigno and Fornaro (2017), Bianchi et al. (2018), Anzoategui et al. (2019), Bolboaca and Fischer (2019), Moran and Queralto (2018), and Cozzi et al. (2021). These papers mostly focus on advanced closed economies able to push forth the technological frontier. Some few exceptions are Comin et al.'s (2014) medium frequency two-country model, Roeger et al. (2016) and Cozzi et al. (2021), which allow some degree of technological inflow from abroad, Bolboaca and Fischer (2019), which studies a closed economy adapting an exogenously evolving technological frontier, Ates and Saffie (forthcoming), which extends the model of Klette and Kortum (2004) to a SOE with RBC features, Benigno et al. (2020), which studies the relationship between the surge of capital flows from DC to the United States (US) and the slowdown in global productivity growth, and Queralto (2020), which makes innovation subject to financial frictions in order to study slow recoveries after a financial crisis. However, none of them tackles the issue of a SOE exposed to MNCs' entry and unable to affect the world technological frontier, but undertaking R&D to adapt it to its local circumstances. Yet, most of the countries in the world are of this kind, including several European countries, and thus our model aims to fill this gap in the literature.

Another contribution to this literature is made with the introduction in our model of the preference specification of Schmitt-Grohé and Uribe (2012), which belongs to the class of intratemporal non-separable preferences developed by Jaimovich and Rebelo (2009). The Jaimovich-Rebelo preferences admit two polar cases, the utility function of King et al. (1988) with maximal degree of wealth effect and the preferences formulation with no wealth effect attributed to Greenwood et al. (1988). The estimation of the parameter governing the magnitude of the wealth elasticity of labor supply, based on the full-information approach and using Hungarian data, indicates that the utility function is practically defining the preferences of King et al. (1988). This implies that there is a strong income effect on labor supply, which is in line with the stylized facts for emerging economies (Aguiar and Gopinath, 2007).[6]

Our paper contributes also to the literature that quantifies the role played by capital flows in driving business cycles and growth. Much of the research in this literature aims to reproduce the stylized fact that fast growing, usually poorer, countries experience lower capital inflows, as showed in Gourinchas and Jeanne (2013), while slow growing, often richer, countries receive higher capital inflows. Many of these studies focus on the case of countries in Southern Europe and discuss why the surge in capital inflows in the early 2000s had a detrimental effect on resource allocation and productivity growth. Some recent examples are Reis (2013), Benigno and Fornaro (2012; 2014), Gopinath et al. (2017), and Jaccard and Smets (2020).

Another large body of this literature discusses how the financial integration of less financially-developed countries led to capital outflows from EMs, global imbalances, and a slowdown in frontier productivity (Caballero et al., 2008; Mendoza et al., 2009; Angeletos and Panousi, 2011; Prades and Rabitsch, 2012; Eggertsson et al., 2016; Sandri, 2014; Buera and Shin, 2017, among others).

Most of this theoretical literature abstracts from FDI flows, focusing instead either on aggregate capital flows or on their other two subcategories, namely portfolio investment or debt flows. There are some exceptions though, among which we may enumerate McGrattan and Prescott (2009) and McGrattan (2012), which extend standard growth models by introducing firm-specific technology capital that can be used in multiple countries, and Burstein and Monge-Naranjo (2009) and Ramondo (2014), which develop on the Lucas (1978) span-of-control model and allow for the movement of managerial know-how, interpreted as multinational production (MP). Several other papers introduce both trade and MP to quantify the overall gains from openness. See, e.g., Ramondo and Rodríguez-Clare (2013), which extend Eaton and Kortum's (2002) model to study how the various sources of complementarity and substitutability between trade and MP affect the gains from openness, and Irarrazabal et al. (2013), which builds on the model of Melitz (2003) and is in fact a quantitative application of Helpman et al. (2004) that focuses on understanding the frictions that rationalize export

[6]Queralto (2020) also employs a variant of the preference formulation of Greenwood et al. (1988) that has some similarities with the Jaimovich-Rebelo preferences. However, the author uses the method of minimum distance to estimate the parameter governing the wealth effect and employs data from the South Korean 1997 financial crisis for the estimation.

versus MP decisions. While we abstract from trade and a multi-country setup, our paper is complementary to these aforementioned studies in the literature modeling FDI flows as it allows to investigate the role of MNCs in bringing frontier technology and driving economic fluctuations in a non-frontier SOE, while at the same time to discuss the implications of MNCs presence for domestic R&D.

Another large literature to which this paper relates is the one that proposes quantitative frameworks to study economic fluctuations in EMs. Some prominent examples are: Neumeyer and Perri (2005), Bianchi (2011), Comin et al. (2014), Aguiar et al. (2016), Boileau and Normandin (2017), Houssa et al. (2019), Barrail (2020), Queralto (2020), Ates and Saffie (forthcoming). Among them, our model has some similarities with that of Houssa et al. (2019), which aims to explain business cycle synchronization between an EM, i.e. South Africa, and advanced economies (AEs), i.e. the US or G7, in that both SOE models are able to account for the influence of foreign shocks in the emerging economy and to demonstrate the important role played by these shocks in major crisis episodes. We differ in the categories of shocks considered as we focus on MNCs entry shocks, while Houssa et al. (2019) highlight the importance of commodity and credit supply shocks, and the fact that we introduce endogenous productivity growth in our setup to account not only for business cycle but also medium run fluctuations. With Queralto (2020) and Ates and Saffie (forthcoming) we share, in addition to the modeling approach, the purpose of connecting capital flows to productivity. However, while both models introduce financial frictions to study the dynamics following sudden stops in EMs, our aim is to link FDI with the economic fluctuations in a non-frontier economy. Comin et al. (2014) also introduce FDI but in a two-country model that explores the relative contribution of domestic and US shocks to Mexico's output fluctuations. Our model differs in many aspects but in particular in that we study the interplay between MNCs entry and domestic R&D in driving endogenous productivity in the non-frontier economy.

Finally, our paper is inspired by the empirical literature studying the impact of FDI flows into EMs, in particular those in the CSEE region. Iamsiraroj and Ulubaşoğlu (2015) review 108 empirical studies using data from around the globe and report 880 regression estimates of the effects of FDI on economic growth. The authors find that the distribution of these estimates is such that 43 percent are positive and statistically significant, 26 percent are positive and statistically insignificant, 17 percent are negative and statistically significant, and 14 percent are negative and statistically insignificant.[7] They further investigate the relationship between FDI and output growth using data from a sample 140 countries over the period 1970 to 2009 and find that changes in FDI inflows do generate economic growth. A similar conclusion is drawn by Aizenman et al. (2013) who use cross-country data for 100 countries for the period 1990-2010 and find that the relationship between growth and lagged capital flows depends on the type of flows, economic structure, and global growth patterns. In particular they find a large and robust relationship between FDI and growth, but a weaker and less stable relationship between growth and equity flows. On what concerns the CSEE region, the literature provides also mixed results. Bačić et al. (2004) use aggregate data for the eleven CSEE countries over the period 1994 to 2002 and find that FDI cannot be accounted for the higher economic growth in the CSEE, while Fidrmuc and Martin (2011)

[7] See also Almfraji and Almsafir (2014) for a review of the literature on the relationship between FDI and economic growth.

employing data for the same group of countries between 1995 and 2009 conclude that exports and the stock of FDI in the CSEE region have a significant impact on economic growth. The findings of the latter are confirmed by Hlavacek and Bal-Domanska (2016), who use data for eight CSEE countries covering the period 2000-2012 and show that FDI positively affects economic growth in the CSEE countries, recording a stronger effect between 2009 and 2012.

The effect of FDI on productivity growth has been investigated to a lesser extent by the empirical literature. Kose et al. (2009) employ annual cross-country data over the period 1966 to 2005 for 67 AEs and DCs and find strong evidence that FDI and portfolio equity liabilities boost TFP growth.[8] Bijsterbosch and Kolasa (2010) make an overview of the empirical evidence provided by the literature investigating this relationship in the CSEE countries and, using more recent industry-level data that covers nineteen sectors of eight of the CSEE countries (excluding Croatia, Bulgaria, and Romania) over the period 1995-2005, find that FDI inflows play an important role in driving productivity growth in the CSEE region.

In addition to the analysis of the potential benefits in terms of enhanced output and productivity growth, the empirical literature has also investigated whether capital inflows are an important driver of cyclical fluctuations in the destination countries. In particular, various empirical studies (e.g., Kaminsky et al. (2004), Broner et al. (2013), Lane (2015), Araujo et al. (2017; 2017), and references therein), based on data from a plethora of countries, have documented the fact that capital inflows tend to be procyclical and thus amplify the business cycle fluctuations in DCs and EMs. Our model contributes to this literature as it provides a unified growth and business cycle framework in which we can study the impact of MNCs entry on both the business cycle and the medium-to-long-term fluctuations in output.

2 Motivating Facts

The eleven central- and south-eastern European countries which are members of the EU, the CSEE, attracted about 3 percent of the total world FDI inflows between 1995 and 2019.[9] While this may seem a small share when compared with the almost 40 percent of world FDI inflows that went to the whole Europe in the same period, the importance of FDI flows for the CSEE countries can be better assessed when measured as a share of GDP.[10] Between 1995 and 2019, FDI inflows into the CSEE region averaged 4.15 percent of GDP. In contrast, the world average for the same period was 2.15 percent of GDP. Moreover, the average inflows in the CSEE was higher not only than in the EU15[11] (2.68 percent of GDP), but also

[8] See the references in Kose et al. (2009) for a review of the literature on the relationship between FDI and productivity growth using different levels of data aggregation.

[9] Poland received almost thirty percent of the inflows, being followed by the Czech Republic, Hungary, and Romania, the inward FDI flows to these countries representing slightly more than 70 percent of the group's total.

[10] Data source is the United Nations Conference on Trade and Development (UNCTAD).

[11] The EU15 comprises the following fifteen countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom. These are the EU member countries that joined prior to May 2004. Throughout this paper, the EU15 is used as the representative group of countries for Western Europe and we disregard the withdrawal of the United Kingdom from the EU as this happened in January 2020, while our sample period ends in 2019.

than in both DCs and EMs (2.59 and 2.65 percent of GDP, respectively).[12] As illustrated in Figure 1, FDI inflows to the CSEE region represented a bigger share of GDP than in all the other groups of countries considered for comparison before the Great Recession, but the gap has narrowed afterwards.[13] The biggest gap is observed in the period between the EU accession of most CSEE countries in 2004 and the trough of the global financial crisis in 2009. These large capital inflows helped fund a rapid growth in credit, consumption, and investment, and led to a widening of current account deficits and a buildup of external debt in the CSEE region. The Great Recession exposed the region's vulnerabilities, which reduced its competitiveness in attracting FDI and pushed the CSEE into a deep recession. Since the majority of foreign investors in the CSEE originate in Western Europe, the slowdown of FDI inflows accentuated once several eurozone countries entered the European sovereign debt crisis. The effect was stronger since not only European but also non-European investors feared further contagion in the EU and flocked to safer investments. However, for the past three years covered by our analysis we observe once more the pre-crisis trend, with the CSEE region attracting a larger share of FDI inflows as a percentage of GDP than the other groups of countries considered.

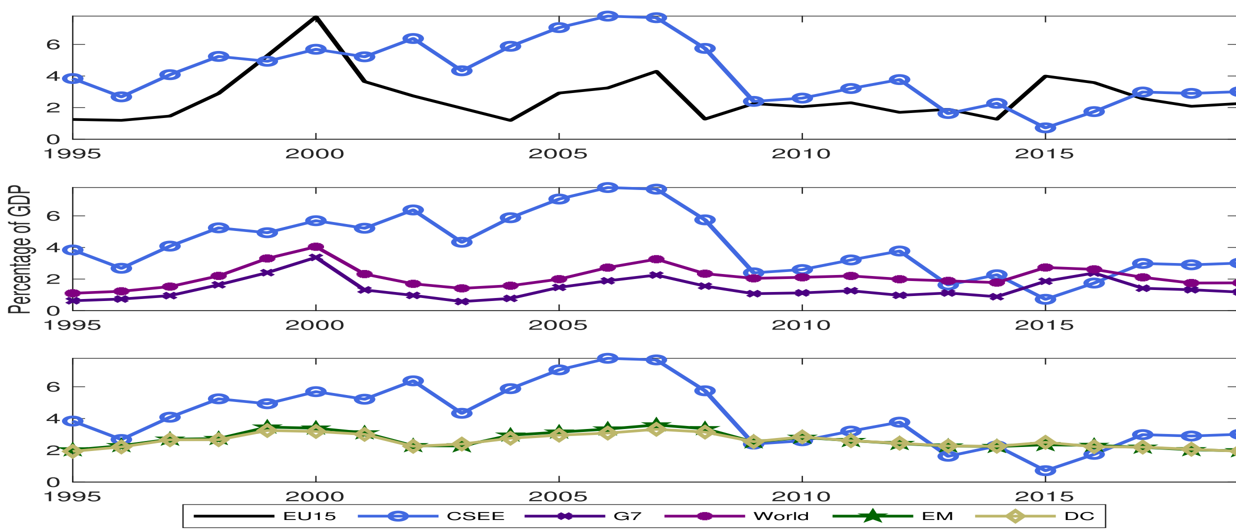

Figure 1: Average inward FDI flows as a percentage of GDP for the period 1995-2019.

The evolution of inward FDI flows and stocks in the CSEE over time is better reflected in Figure 2, where we observe the almost fourfold increase in FDI inflows from 15 billion US dollars in 1995 to 73 billion US dollars at their peak reached in 2007. Even compared to the level of inflows in 2019, the increase is twofold. In the same period, the inward FDI

[12]Note that data for FDI in the EU includes foreign investment of resident special purpose entities (SPEs), which are defined by Eurostat (2018) as enterprises formally registered with a national authority and subject to the fiscal and other legal obligations of the country in which they reside. This may render the stocks and flows of FDI in the EU15 overstated in relation to the economic impact of such investments (see Eurostat (2018) and Dellis et al. (2020) for more details). The presence of SPEs is particularly important for the data coming from Luxembourg, Netherlands, Cyprus, and Ireland. However, this is not the case of the CSEE countries in which the high share of FDI flows relative to GDP reflects the attractiveness of these countries to foreign investors.

[13]Note that the groups are those defined by UNCTAD.

stock of the CSEE group of countries increased from 33 billion US dollars to 827 billion US dollars. As pointed out by Kalotay (2017), what these numbers show is that the CSEE emerged as a new pole of attraction for global FDI within the enlarged EU. Furthermore, as illustrated in Figure 2, between 1995 and 2019 there were larger inward FDI flows than outward flows in the CSEE region, which indicates that the attractiveness of the CSEE region led to more capital flowing into the CSEE countries than out and thus made the region a net FDI recipient.

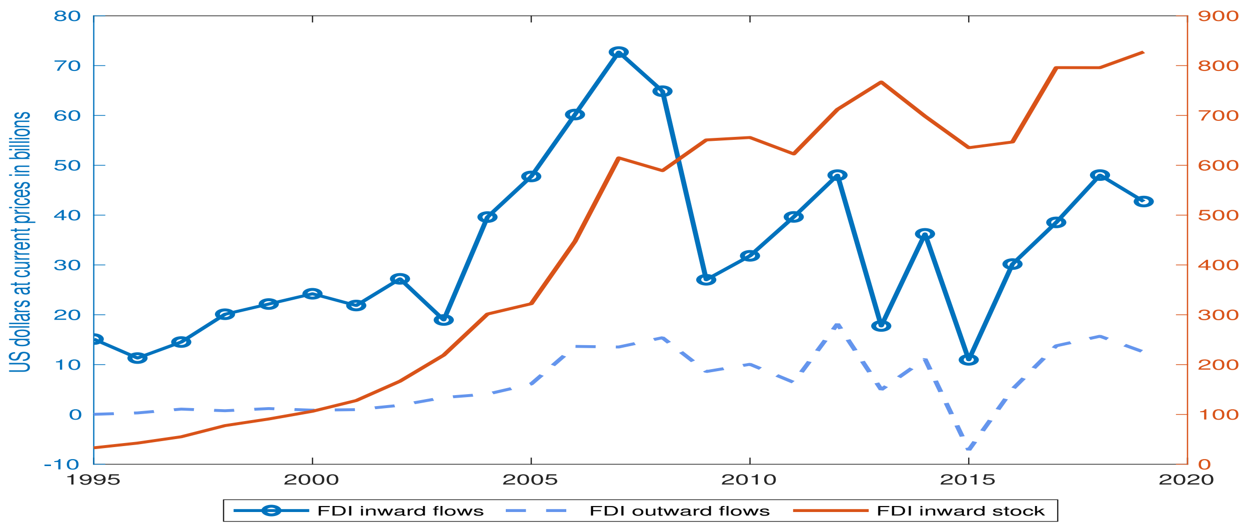

Figure 2: Inward FDI flows and stocks in the CSEE region for the period 1995-2019.

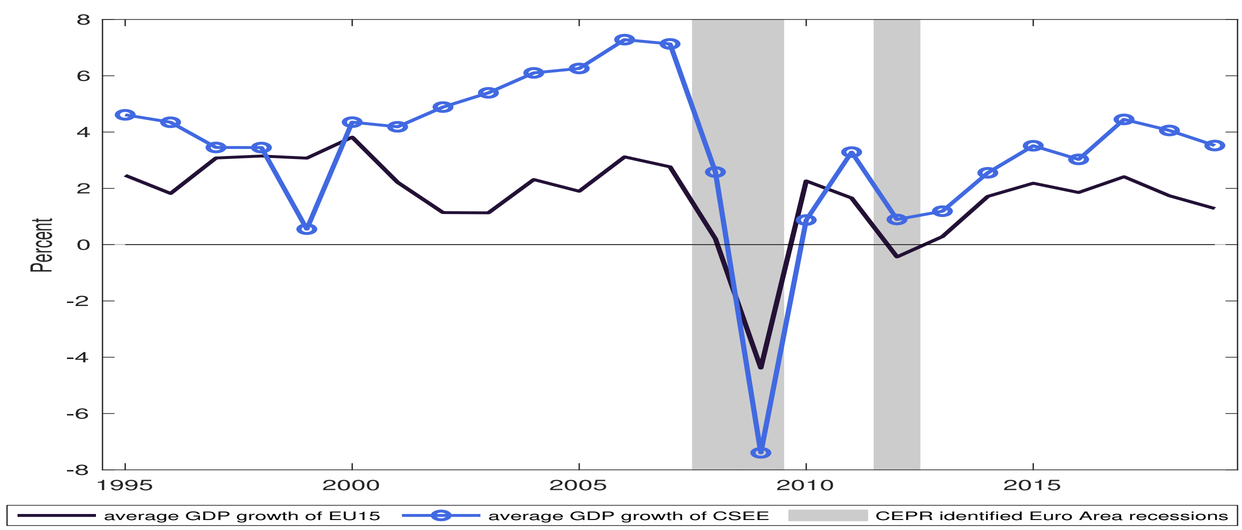

Figure 3: Comparison of GDP growth rates for the sample period 1995-2019.

There is a growing empirical literature that investigates the effects of international capital flows, in particular of FDI, on output and productivity growth in the CSEE. The reason is that these countries did not only experience large FDI inflows but also entered a process of catching-up with Western Europe after the collapse of the communist regimes in the region in the mid-1990s and their consequent transition to market economies (Bijsterbosch and Kolasa, 2010). In the years that followed the CSEE recorded significant economic growth and productivity gains. As it can be observed in Figure 3, real GDP of the CSEE grew at twice the speed of the EU15 GDP between 1995 and 2019.[14] The higher average growth rate of the CSEE region indicates that there is an economic convergence towards the income levels of the most advanced Western European countries, even though the catching-up process has been slowed down by the global financial crisis.

One of the main contributors to the economic development of the CSEE region is considered to be productivity, which has experienced an acceleration in the same period (Georgiev et al., 2017). The average annual TFP growth was about 1.1% between 1995 and 2019 in the CSEE region, while it recorded an average of almost -0.1% in EU15 in the same period, which indicates that productivity in the CSEE countries grew faster than in the EU15.[15] In Figure 4 it can be observed not only the difference between the productivity growth rates of the two main subgroups of the EU, but also the similarity to the evolution of output growth rates in these two regions which are displayed in Figure 3. Furthermore, there is empirical evidence which indicates that technological progress has been the main driver of the strong economic growth in the CSEE region before the Great Recession.[16]

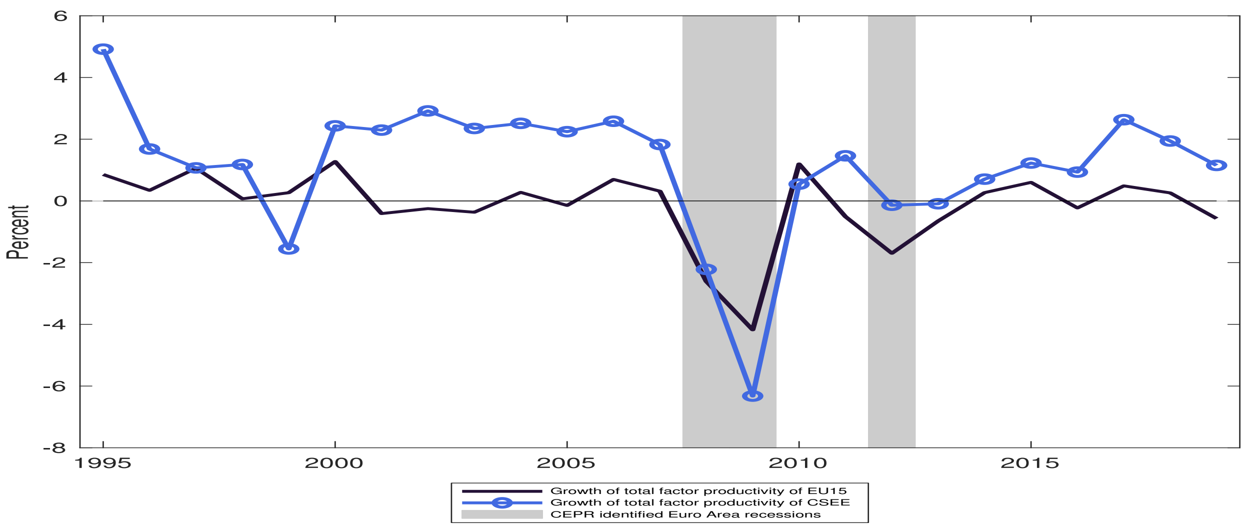

Figure 4: Comparison of productivity growth rates for the sample period 1995-2019.

However, domestic innovation does not seem to be much accountable for this economic performance. The reason is that gross domestic expenditure on R&D in the CSEE region has been significantly lower than in the average European country between 1996 and 2018. Specifically, the CSEE countries invested on average less than one percent of GDP on R&D

[14]Data source is UNCTAD.

[15]Data source is the the Total Economy Database (TED-2: Growth Accounting and Total Factor Productivity for 1990-2019, as of July 2020.

[16]See Levenko et al. (2017) for an analysis of the contributions to output growth of capital, employment, capacity utilization, and utilization-adjusted TFP growth before, during, and after the global financial crisis using CSEE data for the sample period 1996-2016.

projects in this period,[17] while the average for the EU15 group of countries was about two percent of GDP. At the same time, the European and the world averages were close to 1.7 and 1.6 percent of GDP, respectively. The value of the R&D expenditure in the CSEE represented about 5.6 percent of the total expenditure made in the EU and 1.2 percent of the world total R&D expenditure.[18] One may think that as the CSEE countries were and still are on average lagging behind those in the EU15 in terms of productivity levels, increased investment in domestic innovation in this region may have a higher marginal effect on productivity than in the rest of the EU. Nevertheless, when computing the cross-correlation between the growth rates of TFP and R&D expenditure, we find no evidence in favor of a lead-lag effect.[19] In contrast, we find positive cross-correlations between inward FDI flows and different measures of productivity.[20] This contradicts Gourinchas and Jeanne (2013) who conclude that capital does not flow more to countries that grow faster. The situation of the countries in the CSEE region seems to be different than that of the DCs considered in the analysis of Gourinchas and Jeanne (2013) as they experienced higher productivity growth and at the same time attracted more capital between 1995 and 2019. While Gourinchas and Jeanne (2013) find that capital has been flowing "upstream" from DCs to the US, in the case of the CSEE we find that capital moved "downstream" to the poorer CSEE countries, investment coming mostly from the richer EU15 neighbors.

To conclude, the CSEE countries are a good example of non-frontier economies that have experienced strong economic growth and productivity gains accompanied by large FDI inflows but in the absence of considerable improvement in domestic innovation. While simple correlations of raw data point to the existence of a positive relationship between economic performance and FDI inflows, the empirical literature provides mixed results which depend on the econometric approach employed, sample of countries considered, data, and time span chosen. For this reason, to further investigate whether and to what extend MNCs' entry and R&D are sources of economic fluctuations in non-frontier economies, we employ a standard DSGE model for a SOE enriched with endogenous adoption of an exogenously evolving technological frontier developed abroad, which we describe in the next section.

Among the CSEE countries, we choose Hungary for our quantitative application of the model. Our choice was motivated by the fact that Hungary is the CSEE country with the largest share of MNCs in the business sector in terms of value added, production, and turnover.[21] For example, in 2014 foreign penetration in terms of value added reached 53 percent in Hungary, more than 40 percent in the Czech Republic, Romania and Slovakia,

[17] Gross domestic expenditure on R&D (GERD) as a percentage of GDP is the total intramural expenditure on R&D expressed as a percentage of GDP. Data source is UNESCO Institute of Statistics (UIS).

[18] Total intramural R&D expenditure is measured in million purchasing power standards (PPS) at 2005 prices. Data source is UIS.

[19] We consider lags from 4 to 11 years and find no consistent pattern that could indicate that changes in lagged growth rates of R&D expenses lead to higher productivity growth.

[20] We compute the cross-correlation between FDI inward flows as percentage of GDP and growth of TFP, growth of real labor productivity per person employed, or growth of real labor productivity per hour worked. The coefficients of correlation vary between 0.3 and 0.6 depending on the productivity measure employed. Data source for real labor productivity is Eurostat.

[21] We use data from Eurostat for foreign-owned companies (FATS dataset) and for all firms (SBS dataset) in the CSEE countries to investigate how important the MNCs are for the domestic economy and how they compare with local firms.

and less than 30 percent in Croatia, Poland and Slovenia. Moreover, as displayed in Table 6 in Appendix A, regardless of the indicator considered, the shares of MNCs in the Hungarian economy have been relatively stable over the period 2008-2018,[22] which is in line with the assumption in Saffie et al. (2020) that Hungary reached a financially open steady state in 2008. Further details on the importance of MNCs in the CSEE region are provided in Appendix A.

3 The Model

In this section, we set up the model of our stylized non-frontier small open economy, which is cast in an infinite horizon in discrete time, $t = 0, 1, 2, ...$, with all agents having perfectly rational expectations. Growth is given by the evolution of the technological frontier $A_t^{\max}$, which fluctuates exogenously around a deterministic trend rate $g_{\text{exo}} > 0$.[23]

The economy is populated by households, goods producers, domestic innovators, multinational companies, and the government. Households, who are identical, consume the final good, invest in capital and R&D, and supply labor services to intermediate goods producing firms. Manufacturing is realized in two sectors. The final good producing sector is represented by competitive final goods producers, which combine the output of a continuum of intermediate goods producers. The intermediate goods producing sector operates under monopolistic competition and employs capital and labor services in its goods production. Domestic innovators use the R&D investment provided by households to produce a probability of filling the gap between their sectorial productivity and the technological frontier by targeting an intermediate technological level. A novelty of our model is that we allow foreign companies, in addition to domestic innovators, to enter the country and modernize the domestic industries. More specifically, we assume that, after domestic R&D takes place in a given sector, a multinational firm equipped with the frontier technology can enter the sector with an endogenous probability that depends on foreign direct investment. Lastly, the government's role is to partially fund the R&D expenditures of innovators and uses lump-sum taxes for this purpose. We further present their optimization problems in turn.

3.1 Manufacturing

A unique final good Y_t is produced at time t by perfectly competitive firms, which combine a continuum (normalized to a mass of 1 without loss of generality) of intermediate goods $i \in [0, 1]$ according to a constant returns to scale (CRS) production function

$$Y_t = \exp(\epsilon_t^{\text{temp}}) \left(\int_0^1 Y_{it}^{\frac{\xi-1}{\xi}} di \right)^{\frac{\xi}{\xi-1}}, \tag{1}$$

[22]Data source is the Hungarian Central Statistical Office.

[23]We discard population growth in this model because population has been shrinking in Hungary during the period considered in this paper, population decline being attributed not only to low birth rates but also to large out-migration. As migration can be reverted and the time series are not sufficiently long, it is not advisable to consider the trend observed in the past years as the steady state growth rate of population in this country.

with constant elasticity of substitution (CES) $\xi > 1$, and subject to a temporary disembodied productivity shock ϵ_t^{temp}.

It easily follows that the demand function for each intermediate good is

$$Y_{it} = Y_t \left(\frac{P_{it}}{P_t} \right)^{-\xi}, \tag{2}$$

where P_t is the general price index

$$P_t = \left(\int_0^1 P_{it}^{1-\xi} di \right)^{\frac{1}{1-\xi}}. \tag{3}$$

Since we will focus on real variables, we normalize the final goods price index to 1.

The intermediate goods are produced under monopolistic competition. Each intermediate good i is produced using capital K_{it-1} and labor l_{it} according to a technology represented by the following Cobb-Douglas production function:

$$Y_{it} = A_{it} \left(l_{it} \right)^{\alpha} \left(\frac{K_{it-1}}{A_t} \right)^{1-\alpha}, \tag{4}$$

where α is labor elasticity, A_{it} is sector i's technological level, and $A_t = \int_0^1 A_{it} d\, i$ denotes aggregate technology. As in Howitt and Aghion (1998), Nuño (2011), and Cozzi et al. (2021), with more sophisticated technologies, production becomes more capital-intensive. The intermediate good i's firm decides on the selling price, taking the demand of the final goods producer as given. Thus, its unconstrained profit maximizing price is

$$P_{it} = \frac{\xi}{\xi - 1} MC_{it},$$

with $\frac{\xi}{\xi-1}$ providing the mark-up over real marginal costs, MC_{it}.

Moreover, the intermediate good i's firm hires labor and capital, taking the real rental cost of capital, r_t^K, and W_t, the real wage, as given. Hence the factor demands of intermediate good i's producer are obtained by solving the following profit maximization problem

$$\max_{K_t, l_t} D_{it} = P_{it} Y_{it} - W_t l_{it} - r_t^K K_{it-1}.$$

Therefore, the demand equation for capital is

$$r_t^k = MC_{it} (1 - \alpha) \frac{Y_{it}}{K_{it-1}},$$

and for labor is:

$$W_t = MC_{it} \alpha \frac{Y_{it}}{l_{it}},$$

In a symmetric equilibrium, intermediate goods producing firms hire capital and labor in the same ratio, which in turn equals the average ratio because they face the same factor prices. Therefore, they have the same real marginal cost, $MC_{it} = MC_t$. Going back to the pricing rule, having the same marginal cost, firms also charge the same price. From the demand specification, if all firms charge the same price, they must produce the same amount of output. Averaging sector i's production function

$$Y_{it} = \frac{A_{it}}{A_t} \left(A_t l_{it}\right)^{\alpha} \left(K_{it-1}\right)^{1-\alpha},$$

and integrating over all sectors gives

$$Y_t = \exp(\epsilon_t^{\text{temp}}) \left(A_t l_t\right)^{\alpha} \left(K_{t-1}\right)^{1-\alpha},$$

which implies a standard growth accounting relationship

$$g_{Y_t} = \alpha g_{A_t} + (1-\alpha) g_{K_{t-1}}. \tag{5}$$

Since in the deterministic trend (balanced growth path) growth rates are constant, i.e. $g_{A_t} = g_A = g_{\text{exo}}$, and $g_K = g_Y$, from eq. (5) it follows that

$$g_K = g_Y = g_{\text{exo}},$$

meaning that the trend growth rate of capital and GDP - and therefore that of investment and consumption - are all equal to the deterministic growth rate of frontier productivity. These considerations will be very useful when we recast our model in stationary form, which is required for numerical simulations.

Using these findings, we can rewrite the labor and capital demand equations in aggregate terms as it follows

$$r_t^k = \frac{\xi - 1}{\xi}(1-\alpha)\frac{Y_t}{K_{t-1}},$$

$$W_t = \frac{\xi - 1}{\xi}\alpha\frac{Y_t}{l_t}.$$

3.2 Households

In this economy there is a unit continuum of identical households. The generic household $j \in [0,1]$ maximizes its intertemporally additive utility function

$$U_{jt} = \mathbb{E}_t \sum_{s=0}^{\infty} \exp(\epsilon_{t+s}^{\text{beta}}) \beta^s u\left(C_{j,t+s}, l_{j,t+s}, S_{j,t+s},\right),$$

where the discount factor has a constant component $0 < \beta < 1$ and a normally distributed stochastic component driven by an exogenous shock ϵ_t^{beta}, which allows fluctuations in the time preference of households and thus affects both the marginal utility of consumption and the marginal disutility of labor.

The period utility $u\left(C_{jt}, l_{jt}, S_{jt}\right)$ is a standard constant relative risk aversion (CRRA) utility function

$$u\left(C_{jt}, l_{jt}, S_{jt}\right) = \frac{\left(C_{jt} - hC_{jt-1} - \omega\theta^{-1} l_{jt}^{\theta} S_{jt}\right)^{1-\sigma} - 1}{1-\sigma}, \tag{6}$$

which depends on household's consumption spending C_{jt}, labor supplied l_{jt}, and S_{jt}, defined as a geometric average of current and past habit-adjusted consumption levels according to:

$$S_{jt} = \left(C_{jt} - hC_{jt-1}\right)^{\chi} S_{jt-1}^{1-\chi}. \tag{7}$$

This preference specification is similar to the one in Schmitt-Grohé and Uribe (2012), who introduce internal habit formation in consumption in the class of intratemporal non-separable preferences developed by Jaimovich and Rebelo (2009). The Jaimovich-Rebelo preferences allow the strength of the short-run wealth effects on labor supply to be controlled by $\chi \in [0, 1]$ and hence admit two polar cases, the utility function of King et al. (1988) with maximal degree of wealth effect ($\chi = 1$, $h = 0$), henceforth KPR, and the preferences formulation with no wealth effect ($\chi = 0$, $h = 0$) attributed to Greenwood et al. (1988), henceforth GHH.

As common in the literature, parameter $\sigma > 0$ measures the degree of relative risk aversion, $h \in [0, 1)$ governs the strength of habits in consumption, $\omega > 0$ is the disutility of labor, and $\theta > 1$ determines the Frisch elasticity of substitution of labor when $h = \chi = 0$.

The representative household in each period t receives labor incomes at wage W_t, profits D_{jt} from the $(1-F_t)$ firms they own, obtain interest $(1+r_{t-1})$ from foreign bonds B_{jt-1}, and rental rates r_t^K from their capital stock holdings K_{jt-1}. This income is spent on consumption C_{jt}, physical capital investment I_{jt}, the share $(1 - Z_t)$ of R&D investment X_{jt} that is not refunded by the government in proportion to the R&D subsidy Z_t, lump-sum taxes T_{jt}, and foreign bonds according to the following budget constraint:

$$C_{jt} + I_{jt} + (1 - Z_t)X_{jt} + B_{jt} + T_{jt} = l_{jt}W_t + (1 - F_t)D_{jt} + (1 + r_{t-1})B_{jt-1} + r_t^K K_{jt-1}.$$

The household's law of motion of physical capital is

$$K_{jt} = \exp(\epsilon_t^{\mathrm{MEI}}) I_{jt} \left[1 - \eta_I \left(\frac{I_{jt}}{I_{t-1}}\right)\right] + (1 - \delta)K_{jt-1},$$

where $\epsilon_t^{\mathrm{MEI}}$ represents a marginal efficiency of investment (MEI) shock and $\eta_I \left(\frac{I_{jt}}{I_{t-1}}\right)$ denotes the quadratic adjustment cost to investment paid at time t and defined as

$$\eta_I = \frac{\gamma_K}{2}\left(\frac{I_{jt}}{I_{t-1}} - exp\left(g_I\right)\right)^2,$$

$exp\left(g_I\right)$ being the growth rate of investment along the balanced growth path.[24]

[24]Notice that our timing convention for stocks, similar to that used in *Dynare (2011)* coding, assigns to stock variables the time date when they have been decided. For example, the investment in physical capital available for production in period t is decided at the end of period $t-1$. Therefore, capital used in production at time t is indicated as K_{t-1}. Similarly for B_{t-1}, etc. This makes immediately clear that variables predetermined at time t have been accumulated in $t-1$.

The household's first-order condition with respect to consumption is

$$\Lambda_{jt} = \exp(\epsilon_t^{\text{beta}})(C_{jt} - hC_{jt-1} - \omega\theta^{-1} l_{jt}^{\theta} S_{jt})^{-\sigma} - \beta h \mathbb{E}_t \exp(\epsilon_{t+1}^{\text{beta}})(C_{jt+1} - hC_{jt} - \omega\theta^{-1} l_{jt+1}^{\theta} S_{jt+1})^{-\sigma} - \Pi_{jt}\chi \left(C_{jt} - hC_{jt-1}\right)^{\chi-1} S_{jt-1}^{1-\chi} + \beta h \chi \mathbb{E}_t \Pi_{jt+1} \left(C_{jt+1} - hC_{jt}\right)^{\chi-1} S_{jt}^{1-\chi},$$

where Λ_{jt} and Π_{jt} are the Lagrange multiplier associated with the budget constraint and the law of motion of S_{jt}, respectively.

The household's first-order condition with respect to the risk free bonds is

$$\Lambda_{jt} = \beta \mathbb{E}_t \Lambda_{jt+1}(1 + r_t).$$

The first order condition with respect to labor is

$$\exp(\epsilon_t^{\text{beta}})(C_{jt} - hC_{jt-1} - \omega\theta^{-1} l_{jt}^{\theta} S_{jt})^{-\sigma} \omega (l_{jt})^{\theta-1} S_{jt} = W_t \Lambda_{jt},$$

while for S_{jt} is given by

$$\Pi_{jt} = \exp(\epsilon_t^{\text{beta}})(C_{jt} - hC_{jt-1} - \omega\theta^{-1} l_{jt}^{\theta} S_{jt})^{-\sigma} \omega\theta^{-1} l_{jt}^{\theta} + \beta(1-\chi)\mathbb{E}_t \Pi_{jt+1} \left(C_{jt+1} - hC_{jt}\right)^{\chi} S_{jt}^{-\chi}.$$

In its optimal capital acquisition choice, each household compares the real price of a unit of physical capital, p_t^K, at the end of period t to the expected present discounted value of the next period rental rate of a unit of capital, r_{t+1}^K, plus the expected discounted value of the undepreciated part of capital remaining, $1 - \delta$, weighted by its new price p_{t+1}^K, according to

$$p_t^K \Lambda_{jt} = \mathbb{E}_t \beta \Lambda_{jt+1} \left[r_{t+1}^K + p_{t+1}^K (1 - \delta) \right].$$

Then households optimally choose investment, by equalizing the cost of investment to the price of a unit of capital exclusive of adjustment costs

$$1 = \exp(\epsilon_t^{\text{MEI}}) p_t^K \left[1 - \frac{\gamma_K}{2} \left(\frac{I_{jt}}{I_{t-1}} - exp\left(g_I\right) \right)^2 - \gamma_K \frac{I_{jt}}{I_{t-1}} \left(\frac{I_{jt}}{I_{t-1}} - exp\left(g_I\right) \right) \right].$$

3.3 The R&D Sector

While this model economy characterizes a non-frontier country, its medium frequencies will be affected by the way endogenous domestic R&D adopts the evolving technological frontier developed abroad. More specifically, we will assume that the world technological frontier $A_t^{\max}$ evolves exogenously, with fluctuations around a constant trend growth rate g_{exo}, according to

$$A_t^{\max} = A_{t-1}^{\max} \exp(g_{\text{exo}} + \epsilon_t^{\text{Amax}}),$$

where ϵ_t^{Amax} is a shock process.

3.3.1 Domestic R&D

Domestic innovators use the R&D investment provided by households to produce a probability of filling the gap between their sectorial productivity A_{it-1} and the frontier $A_t^{\max}$ by targeting an intermediate technological level A_{it}^{target} measured by

$$A_{it}^{\text{target}} \equiv A_{it-1} + \phi_{t-1}\left(A_t^{\max} - A_{it-1}\right), \tag{8}$$

with ϕ_t defined as

$$\phi_t = \nu^{\left(1-\frac{A_t}{A_t^{\max}}\right)}, \tag{9}$$

and parameterized by $0 < \nu < 1$. Equation (9) allows the speed of convergence through domestic R&D to depend on the distance to the frontier of domestic average productivity, which is in line with the empirical findings indicating that countries closer to the frontier converge faster. Notice also in equation (8) that in case of success, the domestic innovator's technology will be dependent on the last period's technological level in the sector. This heterogeneity will reflect itself on marginal costs, prices, and production, implying that more advanced incumbents set the stage for higher productivity by domestic innovators in the sector. Each period there is a domestic entrepreneur able to attempt innovation. The success probability of domestic innovation depends on the entrepreneur's R&D expenditure X_{it}, expressed in final goods, according to the following innovation probability production function

$$n_{it} = 1 - \exp\left(-\frac{X_{it}\left[1-\eta_X\left(\frac{X_{it}}{X_{t-1}}\right)\right]}{\varpi^{RD} A_{it}^{\text{target}}}\right). \tag{10}$$

For symmetry to physical capital investment, we assume that R&D investment is subject to a quadratic adjustment cost $\eta_X\left(\frac{X_{it}}{X_{t-1}}\right) = \frac{\gamma_{RD}}{2}\left(\frac{X_{it}}{X_{t-1}} - exp\left(g_X\right)\right)^2$. This captures in reduced form the idea that the past size of R&D laboratories sets a standard for the current research laboratory size, with researchers struggling when imposed abrupt changes.

Note also that, unlike Nuño (2011), we set the probability of innovation n_{it} to be always between 0 and 1 and increasing in R&D expenditure X_{it}, but with decreasing marginal product

$$\frac{\partial n_{it}}{\partial X_{it}} = \frac{1-\eta_X\left(\frac{X_{it}}{X_{t-1}}\right) - \gamma_{RD}\frac{X_{it}}{X_{t-1}}\left(\frac{X_{it}}{X_{t-1}} - exp\left(g_X\right)\right)}{\varpi^{RD} A_{it}^{\text{target}}} \exp\left(-\frac{X_{it}\left[1-\eta_X\left(\frac{X_{it}}{X_{t-1}}\right)\right]}{\varpi^{RD} A_{it}^{\text{target}}}\right).$$

Our R&D production function (10) also features a degree of R&D difficulty that increases with the technological target, A_{it}^{target}, i.e. more sophisticated technologies are more difficult to achieve. This allows us to avoid the prediction of scale effects in adoption.

Moreover, unlike its linear counterparts used by Nuño (2011), Benigno and Fornaro (2017), and other important studies, the ability of this production function to always guarantee a non-negative and lower than 1 probability of innovation allows a lot of flexibility in the analysis of medium term frequencies in non-frontier economies, and sets a basis for several potentially useful theoretical and empirical exercises, including policy evaluations.

3.3.2 Multinational Firms' Entry

However, domestic innovators are not the only ones which can modernize the industries in the country. In fact, we assume that after domestic R&D is spent in sector i, a multinational firm equipped with the frontier technology $A_t^{\max}$ can enter the sector with an endogenous probability f_{it}. Since both domestic and multinational firms operate under constant returns to scale, and given the assumption of price competition, the incumbent firm will exit the sector and the newly entering MNC will bring the frontier technology $A_t^{\max}$ in that sector.

We remark that MNCs may also enter sectors already dominated by a MNC that entered in the past and hence bring the frontier productivity into the sector. Similarly, domestic innovators can challenge MNC incumbents endowed with past frontier technologies, now overcome by the current frontier. Also in this case, the domestic innovator can scale up their sector's productivity by targeting a better technology A_t^{target} determined by equation (8).

For the sake of symmetry, we model the probability of multinational entry f_{it} the same way as the success probability of domestic innovation. Thus, the MNCs' entry probability function depends on the investment M the foreign firm makes to enter the domestic market, i.e. FDI, according to

$$f_{it} = 1 - \exp\left(-\frac{M_{it}\left[1-\eta_f\left(\frac{M_{it}}{M_{t-1}}\right)\right]\exp(\epsilon_t^f)}{\varpi^f A_t^{\max}}\right). \tag{11}$$

As in the case of physical capital and R&D investment, we assume that FDI is subject to the same type of quadratic adjustment cost $\eta_f\left(\frac{M_{it}}{M_{t-1}}\right) = \frac{\gamma_f}{2}\left(\frac{M_{it}}{M_{t-1}} - exp\left(g_M\right)\right)^2$. However, in contrast with the innovation success probability function, the probability of multinational entry is also subject to an exogenous shock ϵ_t^f that captures any stochastic fluctuations due to source or destination country factors that may influence the MNC entry decisions.

The foreign firm's expected profit maximization problem is given by:

$$\max_{M_{it}} f_{it} P_t^{S\max} - M_{it} R_{\text{M}},$$

subject to equation (11), where $P_t^{S\max}$ is the nominal stock market value of the firm at the frontier technology and R_{M} is a constant MNC entry cost.

The first order condition is:

$$P_t^{S\max}\exp\left(-\frac{M_{it}\left[1-\eta_f\left(\frac{M_{it}}{M_{t-1}}\right)\right]\exp(\epsilon_t^f)}{\varpi^f A_t^{\max}}\right)$$
$$\frac{\left[1-\eta_f\left(\frac{M_{it}}{M_{t-1}}\right) - \gamma_f\frac{M_{it}}{M_{t-1}}\left(\frac{M_{it}}{M_{t-1}} - exp\left(g_M\right)\right)\right]\exp(\epsilon_t^f)}{\varpi^f A_t^{\max}} = R_{\text{M}}.$$

From our timing assumption that MNCs enter later in the period after the domestic innovator has attempted the innovation follows that the productivity in each sector i evolves according to the following intra-period lottery:

$$A_{it} = \begin{cases} A_t^{\max}, \text{ probability } f_{it-1}; \\ A_{it-1} + \phi_{t-1}\left(A_t^{\max} - A_{it-1}\right) \equiv A_{it}^{\text{target}}, \text{ probability } n_{it-1}\left(1-f_{it-1}\right); \\ A_{it-1}, \text{ probability } \left(1-n_{it-1}\right)\left(1-f_{it-1}\right). \end{cases}$$

With these timing assumptions, the domestic R&D firm's expected profit maximization is expressed by:

$$\max_{X_{it}} n_{it} P_{it}^{S\text{target}} (1 - f_{it}) - X_{it} (1 - Z_t) R_{\text{RD}} ,$$

subject to equation (10), where $P_t^{S\text{target}}$ is the nominal stock market value of the firm at the target technology and R_{RD} is a constant R&D cost.

The R&D investment first order condition is then:

$$\begin{aligned} P_{it}^{S\text{target}}(1 - f_{it}) \exp \left(- \frac{X_{it} \left[1 - \eta_X \left(\frac{X_{it}}{X_{t-1}} \right) \right]}{\varpi^{RD} A_{it}^{\text{target}}} \right) \\ \frac{\left[1 - \eta_X \left(\frac{X_{it}}{X_{t-1}} \right) - \gamma_{RD} \frac{X_{it}}{X_{t-1}} \left(\frac{X_{it}}{X_{t-1}} - exp\left(g_X\right) \right) \right]}{\varpi^{RD} A_{it}^{\text{target}}} \\ = (1 - Z_t) R_{\text{RD}} . \end{aligned}$$

Hence:

$$\frac{X_{it} \left(1 - \eta_X \left(\frac{X_{it}}{X_{t-1}} \right) \right)}{\varpi^{RD} A_{it}^{\text{target}}} = \ln \left(\frac{P_{it}^{S\text{target}} (1 - f_{it}) \left[1 - \eta_X \left(\frac{X_{it}}{X_{t-1}} \right) - \gamma_{RD} \frac{X_{it}}{X_{t-1}} \left(\frac{X_{it}}{X_{t-1}} - exp\left(g_X\right) \right) \right]}{\varpi^{RD} A_{it}^{\text{target}} (1 - Z_t) R_{\text{RD}}} \right) . \tag{12}$$

In equilibrium firm values are proportional to their productivity index, which implies that

$$\frac{P_{it}^{S\text{target}}}{A_{it}^{\text{target}}} = \frac{P_t^S}{A_t^{\text{target}}} = \frac{P_t^{Smax}}{A_t^{\max}}, \text{ for all } i \in [0, 1],$$

where P_t^S denotes the value of an average intermediate good monopolist in this economy. Therefore equation (12) becomes

$$\frac{X_t \left(1 - \eta_X \left(\frac{X_{it}}{X_{t-1}} \right) \right)}{\varpi^{RD} A_t^{\text{target}}} = \ln \left(\frac{P_t^S (1 - f_{it}) \left[1 - \eta_X \left(\frac{X_{it}}{X_{t-1}} \right) - \gamma_{RD} \frac{X_{it}}{X_{t-1}} \left(\frac{X_{it}}{X_{t-1}} - exp\left(g_X\right) \right) \right]}{\varpi^{RD} A_t^{\text{target}} (1 - Z_t) R_{\text{RD}}} \right) .$$

Notice from the term $1 - f_{it}$ that the risk of a MNC's vanifying the R&D investment of a domestic innovator will discourage domestic R&D investment.

Due to the two sources of creative destruction in our model economy, domestic and MNC innovations, the (average) stock market value of an incumbent intermediate good monopolist is expressed by the present discounted value of next period's dividends plus the continuation value of this firm scaled down by the lower than 1 probability of it not becoming obsolete due to domestic or foreign competition. Therefore its stock market valuation, after taking into account the household's stochastic discount factor, is:

$$\Lambda_t = E_t \left[\beta \Lambda_{t+1} \frac{D_{t+1} + P_{t+1}^S (1 - n_{it+1}) (1 - f_{it+1})}{P_t^S} \right] .$$

3.4 Sectorial Dynamics and Productivity Growth

Each sector will alternate the nationality of its leader based on the realization of the innovative entry processes. Therefore we cannot determine the nationality of the incumbent of a sector at a given time. However, since all innovative entry processes are assumed to be independent, we can appeal to the law of large number and use them to study the average frequency of sectorial incumbency changes, which is indeed deterministic. Remembering that multinationals can enter also sectors already dominated by a (potentially obsolete) multinational entered in the past, it follows that MNCs control a subset of the sectors of the economy of mass F_t, which evolves according to the following law of motion:

$$F_t = F_{t-1} + (1 - F_{t-1})f_{t-1} - F_{t-1}(1 - f_{t-1})n_{t-1}.$$

By aggregating the domestic and foreign innovations over the economy, and using the law of large numbers again, we can conclude that the average domestic technology evolves deterministically according to the following difference equation:

$$A_t = f_{t-1}A_t^{\max} + (1 - f_{t-1}) \left\{ n_{t-1} \left[A_{t-1} + \phi_{t-1} \left(A_t^{\max} - A_{t-1} \right) \right] + (1 - n_{t-1})A_{t-1} \right\}.$$

3.5 Foreign Assets

This small open economy can free trade its homogeneous final good with the rest of the world at the price of 1. However, we do not restrict this country to always have a balanced trade, but rather allow it to accumulate net foreign assets or liabilities. Since there are various sources of fluctuations in this economy, the possibility of accumulating and decumulating net foreign assets allows its households to smooth consumption by borrowing in bad times and lending in good times. In this section we will then describe the asset and current account dynamics. Net foreign assets are expressed in terms of the household's net stock of foreign bonds, which in the aggregate evolves according to the following equation:

$$B_t = (1 + r_{t-1})B_{t-1} - D_t F_t + TB_t,$$

where TB_t denoted the domestic country's trade balance in period t. Trade balance is measured by the difference between the country's production of the final good and its aggregate expenditure in physical and R&D investment and consumption:

$$TB_t = Y_t - C_t - I_t - X_t.$$

Notice that we assume that households can, via a costless financial sector, also issue such bonds to finance their debt: hence, by consolidating all household's positions, country's net foreign liabilities will be represented by negative values of B_t. The real interest rate on foreign assets or liabilities is

$$r_t = \bar{r} + \psi \left[\exp \left(\frac{\bar{B}}{\bar{Y}} - \frac{B_t}{Y_t} \right) - 1 \right],$$

where $\bar{r}$ is the steady state rest of the world interest rate, and $\psi > 0$ is the sensitivity parameter of the external debt elastic interest rate premium assumed here as in Schmitt-Grohé and Uribe (2003). This allows us to study economic fluctuations of our small open economy using linear approximations in a relatively simple way, under the realistic assumption that if domestic assets are lower than a steady state ratio to GDP $\frac{\bar{B}}{\bar{Y}}$, or domestic liabilities are too high, then the country will have to pay an interest rate risk premium $\psi\left[\exp\left(\frac{\bar{B}}{\bar{Y}}-\frac{B_t}{Y_t}\right)-1\right]$.

The current account is obtained from the trade balance, by adding the incomes from foreign bonds and subtracting the dividends paid to the foreign owned firms (MNCs), that is:

$$CA_t = TB_t - D_tF_t + r_{t-1}B_{t-1}.$$

Notice that if the steady state foreign assets/liabilities are zero, the current account will be zero as well, while the trade balance will be positive and equal to the total dividends paid to the owners of the multinational firms.

3.6 Government

The government finances a part of the R&D investment performed by domestic innovators. The share of domestic R&D investment, Z_t, fluctuates stochastically according to shock ϵ_t^{RD}:

$$Z_t = Z\exp(\epsilon_t^{RD})$$

around a deterministic steady state value $Z \in (0,1)$, with ϵ_t^{RD} following an AR(1) process.

The government raises revenue via lump sum taxes collected from households to finance its expenditures:

$$Z_tX_t = T_t,$$

3.7 Shocks

As previously mentioned, there are six exogenous sources of fluctuations in this economy: a shock to the frontier technology ϵ_t^g, a temporary productivity shock ϵ_t^{temp}, a shock to the household's intertemporal preferences ϵ_t^{beta}, a marginal efficiency to investment shock ϵ_t^{MEI}, a MNCs' entry rate shock ϵ_t^f, and a shock to R&D government investment subsidy, ϵ_t^{RD}, which follow an autoregressive process of order 1 and are described by the following equations:

$$\begin{aligned}
\epsilon_t^{\text{temp}} &= \rho_{\text{temp}}\epsilon_{t-1}^{\text{temp}} + u_t^{\text{temp}}, \\
\epsilon_t^{\text{beta}} &= \rho_{\text{beta}}\epsilon_{t-1}^{\text{beta}} + u_t^{\text{beta}}, \\
\epsilon_t^{MEI} &= \rho_{MEI}\epsilon_{t-1}^{MEI} + u_t^{MEI}, \\
\epsilon_t^{f} &= \rho_{f}\epsilon_{t-1}^{f} + u_t^{f}, \\
\epsilon_t^{g} &= \rho_{g}\epsilon_{t-1}^{g} + u_t^{g}, \text{ and} \\
\epsilon_t^{RD} &= \rho_{RD}\epsilon_{t-1}^{RD} + u_t^{RD}.
\end{aligned}$$

4 Estimation and Evaluation of the Model

In this section we analyze and simulate the model after setting numerical parameters. We solve the model numerically using a first order perturbation method. We use the solution to the linear approximation of the detrended model around its deterministic steady state to find the equilibrium values of variables.[25] The parameters are set using both calibration and Bayesian estimation techniques.[26] We first discuss the calibration procedure and then continue with the estimation approach.

4.1 Calibration

We calibrate the steady state growth rate of the frontier technology to 0.9275/400 in order to match the roughly 0.9275 percent annual growth rate of TFP in the US over the period 1995Q2-2019Q4.[27]

We then fix the steady state gross real interest rate of the rest of the world to match an annual rate of 6 percent in the US, which we choose to be close to the mean after-tax return on business capital during the chosen sample period.[28] To satisfy the Euler equation, β equals 0.9875.

Parameter α is set equal to 0.56. We choose the calibration based on the average value of the share of labor compensation in Hungarian GDP at market prices over 1995-2019.[29] While the value for this parameter is smaller than the usual calibration of 2/3, it must be considered that this standard calibration in macroeconomic models is usually made for the US and using an average for a much longer timespan. Nevertheless, as discussed in Karabarbounis and Neiman (2013), the decline of the labor share has been registered in the majority of countries and industries since the 1980s, the main reason being a decrease in the relative price of investment goods that induced firms to shift away from labor and toward capital.

For the depreciation rate, δ, we set a value of 0.04/4, which implies an annual rate of depreciation of capital equal to 4 percent. This value of δ is the average depreciation rate of the capital stock for the period from 1995 to 2017 in Hungary.[30]

We set the labor disutility parameter ω such that the steady state share of consumption in output is about 53%, which is the average share for the period 1995Q2-2019Q4 based on data from Eurostat.[31]

We choose for σ, the parameter that defines the curvature of the period utility, a value

[25] See Appendix B for a description of the stationarized model.

[26] See An and Schorfheide (2007) for an overview of the literature on Bayesian estimation methods for DSGE.

[27] We use the quarterly-TFP series for the US Business Sector, produced by John Fernald (version of March 05, 2020 and downloaded on November 12, 2020), as described in Fernald (2014)

[28] As reported in Gomme et al. (2015), the return to capital was about 6 percent since 1995, it fell below 5 percent during the Great Recession, but rebounded afterwards to almost 7 percent in 2014.

[29] Annual data is retrieved from the Total Economy Database (TED-2: Growth Accounting and Total Factor Productivity for 1990-2019, as of July 2020.) of The Conference Board. A similar result is obtained using data from AMECO for the compensation per employee as percentage of GDP at factor cost per person employed.

[30] The average annual depreciation rate of the capital stock is retrieved from the Penn World Table, version 9.1 (Feenstra et al., 2015).

[31] We use GDP and main components (output, expenditure, and income) data from the dataset coded [$namq\_10\_gdp$] of Eurostat.

of 2,[32] which is a calibration often used in the macroeconomics literature.[33]

Moreover, we calibrate $\theta = 2$, which implies that the Frisch labor supply elasticity is equal to 1 when $h = \chi = 0$.[34] We further calibrate steady state hours worked equal to 1/3, to match the fact that, according to the Labor Law in Hungary (Labour Code Art. 92 Sec 1), the standard working time is eight hours a day, which is equivalent to one third of the working day.

To calibrate the steady state value for the success probability of domestic innovation, n, we follow the approach of Comin and Gertler (2006) and consider the average time for the adoption of an intermediate good to be the inverse of this probability. For the US, it is standard to assume an adoption lag of about 10 years, given that between 1820 to 2003 in the US technologies needed about 19.8 years to be adopted (Comin and Hobijn, 2004; Comin et al., 2008; Comin and Hobijn, 2010; Comin and Mestieri, 2018). However, when considering the group of technologies that were invented after 1950 (i.e. cell phones, personal computers, internet usage, etc.), the average becomes 6.7 years (Eden and Nguyen, 2016). Since, for the case of Hungary we have data at most starting from 1995, and knowing that recent technologies are adopted faster than in the past, we assume an average adoption lag of 5 years in the US and adjust this value depending on the technology capability of Hungary relative to the US.[35] Using the sub-indices computed by Radosevic and Yoruk (2015) for technology capability in 42 countries, we obtain a scale of about 1/4 for Hungary.[36]

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[32] We choose to calibrate this parameter instead of estimating it since the inclusion of this parameter in the list of estimated parameters makes χ, the parameter governing the magnitude of the wealth elasticity of labor supply, weakly identified. Since we do not have data for wages and employment to include as observables in the model and there is less econometric evidence on the value of χ, we prefer to estimate χ rather than σ. However, when applying the numerical optimizers to find the posterior mode of σ, based on a prior Gamma distribution centered at 4 and with a standard deviation of 1.5, we obtain a value of about 2.5, which is not significantly different from our calibration.

[33] Most estimates of this parameter lie between 0 and 5, with 1, equivalent to a logarithmic utility, and 2, which indicates a higher degree of concavity, being the most common. Our calibration is motivated by Gandelman and Hernandez-Murillo (2015), who estimate the CRRA for 75 countries using data on self-reports of personal well-being from the Gallup World Poll. They find that estimates for both developed and DCs are concentrated in the vicinity of 1. However, the distribution of estimates for advanced countries contains relatively more mass of observations between 0 and 0.5, while the distribution for less advanced economies contains relatively more observations around 2. See Chetty (2006) and Barseghyan et al. (2018) for a survey of the literature on estimating risk preferences.

[34] Since estimates of the Frisch elasticity vary depending on the data and approach used for the estimation, with more recent estimates based on macro data indicating that the estimate is in the interval 1 to 2 (for details see Fiorito and Zanella, 2012, and Keane and Rogerson, 2012), or below 1 in the micro literature, we choose a value of 1 as a compromise between these findings (see Peterman, 2016, for a discussion of what explains the gap between the micro and macro estimates of the Frisch elasticity). Ríos-Rull et al. (2012) also indicate that results based on a Frisch elasticity of 0.72 or 1 are the most credible ones.

[35] A shorter adoption lag in the US, e.g. 5 years, is also assumed in other recent papers such as Anzoategui et al. (2019).

[36] We use the technology capability component of the first dimension, i.e. intensity of technology upgrading by types, of the composite technology upgrading index developed by Radosevic and Yoruk (2015) and Radosevic and Yoruk (2016). The intensity of technology upgrading by types dimension contains three components: production capability, technology capability and R&D capability. While there are no clear boundaries between the three components, some differences can be highlighted. For example, the production capability is more about producing efficiently and generating incremental innovations through improvements in products and processes. Technology capability differs in the sense that it performs advanced development

Using data from the Hungarian Central Statistical Office, we calibrate the steady state share of sectors dominated by multinationals equal to the average share of MNCs in the economy based on value added for the period 2008-2018.[37] Hence, the steady state value of variable F is 0.5. [38] Plugging the steady state values for F and n in the equation defining the dynamics of the set of sectors dominated by MNCs, we obtain that the long-term probability of MNCs' entry, f is about 1.24 percent per quarter.[39]

We employ data from Eurostat to set the steady state value of business expenditure on R&D (BERD) X as 0.6 percent of output.[40] and the R&D subsidy provided by the government to 11.5 percent of BERD.[41] We further calibrate the R&D difficulty parameter and the R&D cost in order to match these moments.

We use data on FDI flows into Hungary, excluding special purpose enterprises (SPEs), and total GDP, both in million national currency, to set the steady state value of M equal to 4.15 percent of GDP, which is the average value for the period 1995-2019.[42]

A summary of all parameter values is presented in Table 7 in Appendix C.5.

4.2 Estimation

The estimation of several of the structural parameters of the model is performed using Bayesian methods. We will first describe the observables, then present the prior distribution and posterior estimates, and finish the section with a summary of the estimation results.

4.2.1 Data

We perform the estimation using both quarterly and annual data. The reason is that, while most observables are at quarterly frequency, the series for domestic TFP growth and the share of BERD funded by the government are only available at annual frequency. Nevertheless, the implemented Kalman filter of *Dynare* deals with the missing information and thus allows for the model estimation with mixed frequency data.[43] Our dataset covers the period from

by adapting prototypes for use in manufacturing, while R&D focuses on exploratory development which implies the invention of new prototypes (Radosevic and Yoruk, 2018).

[37] We use the data reported in the STADAT table 3.2.21.

[38] Using data from various OECD publications, e.g. OECD (2002), we constructed the series for 1995-2007 and using also this data the average share becomes 0.48. However, because the two values are relatively close and there were several revisions and methodological changes prior to 2008, we prefer to consider only the sample for the period 2008-2018.

[39] With this calibration, the steady states for the success probability of domestic innovation, n, and the probability of MNCs' entry, f, are almost equal.

[40] We use data from the dataset coded [$rd\_e\_gerdfund$] of Eurostat and from STADAT tables 3.4.3 and 3.4.4 of the Hungarian Central Statistical Office. We divide the series for total R&D performed by the business sector by GDP (both in million national currency) and further average over the period 1995-2019.

[41] We compute the share of R&D performed by the business sector that is funded by the government by dividing the series for the BERD financed by the government by the total BERD. We then report the average between 1995 and 2019.

[42] We use FDI data from the Central Bank of Hungary, Table VIII. Balance of Payments, Foreign Direct Investment, International Investment Position (Foreign Direct Investments, according to BPM6 methodology).

[43] Note that we have also performed the estimation using interpolated quarterly series derived from the annual series and the estimation results are similar.

1995Q2 to 2019Q4.

Our vector of observable variables is

$$\left[g_t^{\text{qobs}}, \Delta \ln Y_t^{\text{qobs}}, \Delta \ln C_t^{\text{qobs}}, \Delta \ln I_t^{\text{qobs}}, \Delta \ln A_t^{\text{aobs}}, Z_t^{\text{aobs}}\right],$$

where Δ denotes the temporal difference operator and the superscript indicates that the variable is observed at either quarterly *qobs* or annual frequency *aobs*. The time series of observed variables as introduced in the estimation are displayed in Figure 5.[44]

The model is set at quarterly frequency. Thus, there is a frequency mismatch between the model and observed variable for domestic TFP growth and the share of BERD funded by the government. In this case, the observation equation describes the relation between the quarterly frequency model variable and the annual frequency observed variable. More specifically, we define the annual observed share of BERD funded by the government as the average of the model quarterly shares in the previous four quarters, i.e.

$$Z_t^{\text{aobs}} = 100\left(Z_t + Z_{t-1} + Z_{t-2} + Z_{t-3}\right)/4,$$

and the annual growth rate of domestic TFP equal to the change in stationarized quarterly average domestic productivity plus the trend growth over the respective year

$$\Delta \ln A_t^{\text{aobs}} = 100\alpha\left(\ln a_t - \ln a_{t-4} + g_t + g_{t-1} + g_{t-2} + g_{t-3}\right).$$

The relationship between the quarterly model variables and observables is given by

$$\begin{aligned}
g_t^{\text{qobs}} &= 100 g_t,\\
\Delta \ln Y_t^{\text{qobs}} &= 100\left(\Delta \ln y_t + g_t\right),\\
\Delta \ln C_t^{\text{qobs}} &= 100\left(\Delta \ln c_t + g_t\right),\\
\Delta \ln I_t^{\text{qobs}} &= 100\left(\Delta \ln i_t + g_t\right),
\end{aligned}$$

Note that $\ln j_t$, where $j = \{y, c, i, a\}$, is the natural logarithm of the respective stationarized variable as described in Appendix B.[45]

[44] Two outliers in the growth rate of consumption (2004Q1 and 2004Q2) and one in the growth rate of investment (2016Q1) were replaced with a three quarters centered moving average.

[45] We also estimated a version of the model with standard i.i.d. measurement errors on the observables, but the standard deviations of these shocks were weakly identified as indicated by various identification checks (see Ivashchenko and Mutschler (2020) for details on the identification diagnostics and tools implemented in *Dynare* and the issues arising from the lack of or weak parameter identification). Moreover, this finding was further confirmed by the fact that after the use of several different numerical optimizers to find the posterior mode, the curvature of the likelihood kernel for these parameters was flat, indicating that none of the measurement errors could be identified from the data. Nonetheless, the estimation of the other model structural shocks and parameters was robust to the inclusion of measurement errors. These results can be provided upon request.

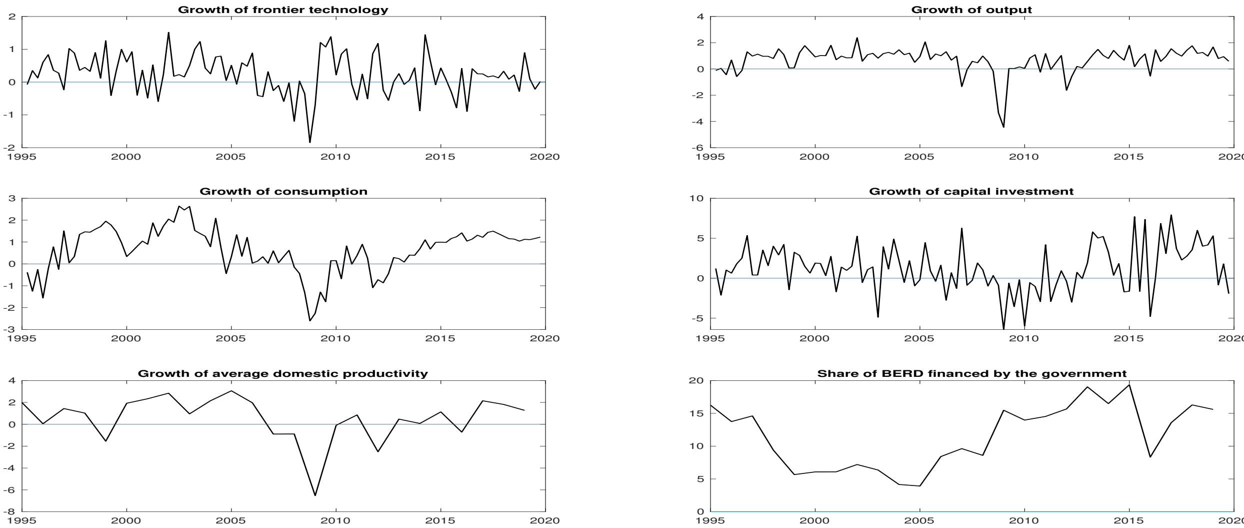

Figure 5: Time series of observed variables as introduced in the estimation.

For the observable of the growth rate of frontier technology, we use the growth rate of TFP in the US, in percent change at a quarterly rate.[46] The series is produced by John Fernald,[47] as described in Fernald (2014).

All quarterly data for Hungary is from Eurostat. We construct real output by diving the nominal series for GDP at market prices by population and the implicit price deflator (2015=100). We proceed similarly to obtain the series for consumption and investment. We use the nominal series for household and NPISH final consumption expenditure, which we divide by population and the implicit price deflator to obtain real consumption. We define real investment as the nominal gross fixed capital formation divided by population and the implicit price deflator.[48] The quarterly log difference of these series are then introduced as observables in the model.

We use the annual growth rate of TFP in Hungary from the Total Economy Database[49] of The Conference Board as a measure of average domestic productivity growth.

As indicated in the previous section, we compute the share of R&D performed by the business sector that is funded by the government by dividing the series for the BERD financed by the government by total BERD.

4.2.2 Priors and Posteriors

The model parameters which we choose to estimate can be grouped into two categories. The first category comprises the parameters that characterize the law of motion of the exogenous

[46] The original series is annualized, but we divide it by 4 to have it at a quarterly rate.

[47] The series is reported in the dataset "Utilization-adjusted quarterly-TFP series for the US Business Sector" (version of March 05, 2020 and downloaded on November 12, 2020), available online at `https://www.frbsf.org/economic-research/indicators-data/total-factor-productivity-tfp/`.

[48] By dividing each nominal series by its implicit deflator, we avoid the mismeasurement issues arising from the use of a common deflator as indicated by Fair (2020).

[49] The data source is TED-2: Growth Accounting and Total Factor Productivity for 1990-2019, as of July 2020.

processes.[50] The second includes the parameters that are harder to be identified based on steady-state relationships among observable variables for Hungary.

As illustrated in Table 1, the priors for the estimated parameters are fairly diffuse and broadly in line with those chosen in the related literature. The prior distributions are displayed in Figure 18 in Appendix C.

To detail upon the choice of priors, for the consumption habit persistence we use a beta distribution centered at 0.7 and with a standard deviation of 0.1 since this parameter is bounded between 0 and 1. We choose the same prior distribution for χ, the parameter governing the magnitude of the wealth elasticity of labor supply, but with a mean of 0.5 and a standard deviation of 0.2 because we have less empirical evidence on the value of this parameter. For the priors of the parameters governing the degree of investment adjustment costs for either capital, R&D, or MNCs' entry, we assume a Gamma distribution centered at 2 and with a standard deviation of 1.5. This is the prior distribution imposed for the capital investment adjustment cost parameter in Smets and Wouters (2007), who were motivated by the findings of Christiano et al. (2005). Our approach only differs in that we choose a prior mean of 2 instead of 4, which is closer to the value chosen in the calibration of RBC models (see, e.g., Jaimovich and Rebelo, 2009). The prior mean for the substitution elasticity across goods is set equal to 5, implying that the gross markup in the goods production sector is centered at 1.25. Similarly to the distribution of the investment adjustment costs, we set the standard deviation equal to 1.5, which implies letting the data quite freely determine the size of these parameters.

For the sensitivity parameter of the interest rate premium ψ and the parameter governing the speed of productivity convergence ν, we use an Inverse Gamma prior distribution to ensure that the estimated parameters remain positive. We follow the approach of Adolfson et al. (2007) and set the prior mean of ψ equal to 0.01 with two degrees of freedom.

The priors for the parameters defining the exogenous processes are defined as in Smets and Wouters (2007). More specifically, the prior distribution for the autocorrelation of all structural shocks is centered at 0.5 and has a standard error of 0.2, while the standard deviation of the innovations is assumed to be Inverse Gamma distributed with a prior mean of 0.10 and a standard deviation equal to 2.[51] By setting rather uninformative priors for these parameters, we let the data determine the importance of the disturbances. This is the usual approach in the estimation of small open economy models (see, e.g., Justiniano and Preston (2010) and Gelain and Kulikov (2011), among others).

The DSGE model is estimated based on observations from 1996:Q1 to 2019:Q4, conditioning on observations from 1995:Q2 to 1995:Q4. We first verify the identifiability of parameters by performing several local identification checks for the estimated parameters at the prior mean. The rank checks of Iskrev (2010), Komunjer and Ng (2011), and Qu and Tkachenko (2012), indicate that all parameters are identified.[52]

[50] Note that the covariance matrix of the innovations is diagonal.

[51] This implies that in terms of the parameters defining an inverse gamma distribution, the location parameter equals 0.0064 and the scale parameter is almost 2, which is equivalent to two degrees of freedom.

[52] Even though all parameters are locally identifiable, the plots of the strength of identification and of the sensitivity component displayed in Figure 12 in Appendix C.1 indicate that parameter γ_{RD} might be weakly identified. This finding is confirmed in Figure 14 in Appendix C.1, which illustrates the parameter groups with the weakest identification. This seems to be due to high collinearity with respect to the effect

Table 1: Prior and Posterior Distribution of Estimated Parameters

	Prior Distribution			**Posterior Distribution**						
Name	**Density**	**Mean**	**S.D.**	**Mode**	**S.D.**	**Mean**	**Median**	**S.D.**	**5%**	**95%**
				Model Parameters						
h	Beta	0.7	0.1	0.855	0.021	0.855	0.856	0.022	0.811	0.894
χ	Beta	0.5	0.2	0.959	0.044	0.931	0.940	0.041	0.850	0.995
ξ	Gamma	5	1.5	7.048	1.083	7.047	6.964	1.155	4.890	9.338
γ_f	Gamma	2	1.5	0.008	0.017	0.025	0.019	0.021	0.000	0.065
γ_{RD}	Gamma	2	1.5	3.399	1.594	4.414	4.143	1.768	1.480	7.951
γ_K	Gamma	2	1.5	5.326	1.986	6.165	6.049	1.643	3.125	9.483
ψ	InvGamma	0.01	2	0.003	0.001	0.003	0.003	0.001	0.002	0.005
ν	InvGamma	0.1	2	0.044	0.063	0.104	0.065	0.167	0.021	0.255
				Autocorrelation Coefficients						
ρ_g	Beta	0.5	0.2	0.249	0.118	0.275	0.269	0.112	0.064	0.490
ρ_{temp}	Beta	0.5	0.2	0.994	0.007	0.989	0.990	0.007	0.975	0.999
ρ_{beta}	Beta	0.5	0.2	0.660	0.094	0.681	0.685	0.096	0.491	0.864
ρ_{MEI}	Beta	0.5	0.2	0.357	0.120	0.357	0.349	0.119	0.135	0.599
ρ_{f}	Beta	0.5	0.2	0.392	0.125	0.347	0.348	0.125	0.105	0.582
ρ_{RD}	Beta	0.5	0.2	0.835	0.072	0.798	0.810	0.080	0.639	0.936
				Standard Deviations of Structural Shocks						
$SE_{u^{\text{g}}}$	InvGamma	0.1	2	0.010	0.001	0.010	0.010	0.001	0.009	0.012
$SE_{u^{\text{temp}}}$	InvGamma	0.1	2	0.014	0.001	0.014	0.014	0.001	0.011	0.016
$SE_{u^{\text{beta}}}$	InvGamma	0.1	2	0.070	0.011	0.078	0.077	0.011	0.058	0.100
$SE_{u^{\text{MEI}}}$	InvGamma	0.1	2	0.173	0.062	0.201	0.197	0.050	0.110	0.304
$SE_{u^{\text{f}}}$	InvGamma	0.1	2	0.207	0.095	0.318	0.291	0.118	0.149	0.549
$SE_{u^{\text{RD}}}$	InvGamma	0.1	2	0.227	0.049	0.260	0.250	0.054	0.171	0.368

We then follow Ivashchenko and Mutschler (2020) in their approach to find the posterior mode and the Hessian evaluated at the mode by sequentially looping over several optimization algorithms, taking the previously found mode as initial value for the next optimizer and starting from the CMA-ES algorithm.[53] We further use a Random-Walk Metropolis-Hastings sampling algorithm to obtain two Markov chains of 600,000 draws from the posterior distribution of the parameters and set the scale parameter such that the acceptance ratio is about one third for each chain.[54] A comparison of the prior and posterior densities is illustrated in Figure 20 in Appendix C.2.

Convergence of the two Markov chains is verified using the univariate and multivariate convergence diagnostics of Brooks and Gelman (1998). Figures 21 to 24 in Appendix C.3 indicate that the chains converge since in each plot the two lines stabilize horizontally and are close to each other. Furthermore, the trace plots illustrated in Figures 25 to 28 in Appendix C.4 are all stable, which confirms that the Metropolis-Hastings converges to a stable distribution.

We discard the first 300,000 draws in each chain as burn-in and sample uniformly 100,000 draws out of the remaining 300,000 to compute the posterior moments that are reported in Table 1. More specifically, Table 1 displays the prior distribution of all parameters, their posterior mode along with the approximate posterior standard deviation obtained from the inverse Hessian at the posterior mode, and lastly, the posterior mean and median along with the the 95% credible intervals. Since the mean and median of the posterior distributions are close for all parameters, we further discuss the results based on the posterior mean.

With the exception of the FDI adjustment costs, the posterior estimates for the parameters governing the role of real rigidities in the model are all far from zero, which indicates that real frictions are important for the model to fit the data. The estimated mean for the consumption habit formation parameter h equals 0.86, indicating that there is strong internal habit persistence in consumption. The value is at the higher end of the region in which most estimates for this parameter lie in the macroeconomic literature, but this is the usual outcome after the estimation of small open economy DSGE models.[55]

Similarly, the mean estimates for the capital and R&D investment adjustment cost parameters are both higher than the prior mean. Among these parameters, the elasticity of capital investment adjustment costs has the highest mean, 6.2,[56] being followed by the elas-

of other parameters on the likelihood, in particular with γ_f and γ_K, as illustrated in Figures 16 and 17 in Appendix C.1. However, since the parameter is not unidentifiable, but only weakly identifiable, we attempt its estimation.

[53] The posterior mode for each estimated parameter is displayed in Figure 19 in Appendix C.2. This figure indicates whether a (local) mode was found, which is, ideally, when the estimated mode is placed at the maximum of the posterior likelihood.

[54] The acceptance rate is 31.08% for the first chain and 30.51% for the second.

[55] See Adolfson et al. (2008) for a comparison of the estimation results for closed and small open economy DSGE models and Havranek et al. (2017) for an extensive analysis of the factors that drive the diversity in the estimates of the habit parameter based on 81 published studies.

[56] The value is higher than the posterior mean of 5.16 obtained by Jakab and Kónya (2016) for an SOE DSGE with nominal rigidities and search-and-matching frictions estimated using data for Hungary. However, it is smaller than the posterior mean of 6.96 obtained by Smets and Wouters (2003) in the estimation of a DSGE for the Euro area. Albonico et al. (2019) show than even when using the same model but different data, the estimates for parameters governing the capital investment adjustment costs differ across countries. Nevertheless, the credible interval for our posterior mean comprises most estimates in the related literature.

ticity for the R&D investment adjustment costs, 4.4, while the one for the FDI adjustment costs is estimated to be almost nil, 0.03. This shows the relatively low variability of capital investment in comparison to R&D investment and especially to inward FDI. The posterior mean of the adjustment costs parameter associated with the investment required for MNCs' entry being close to zero reflects the volatile nature of FDI.

The estimation drives the elasticity of substitution ξ to a larger value than the prior mean, which implies that the price markup of the monopolists is 1.165. While we could not find other estimates for Hungary and for the chosen time span, there is a large pool of estimates for various European countries or group of countries with which we can compare our result. However, the values vary considerably depending on the data and methodology employed. One of the most popular approaches in the recent literature is the cost-based method of De Loecker and Warzynski (2012),[57] which was used by De Loecker and Eeckhout (2017) and De Loecker and Eeckhout (2018) for computing weighted aggregate average price markups for the entire world economy, as well as for individual countries and regions. Using a sample that contains the financial statements of over 70,000 firms in 134 countries starting from 1980, De Loecker and Eeckhout (2018) find that the average global markup increased from close to 1.1 in 1980 to around 1.6 in 2016. While the authors do not report the average values for Hungary, in an illustration of the change in markup between 1980 and 2016, the country is located in the group that registered a decrease to no change in markup. This value is very close to our result, as the estimated posterior mean for the elasticity of substitution gives an average markup for Hungary that is close to the global and European average in 1980.

The posterior mean for the parameter ν is estimated to be equal to 0.1. This implies that the steady state probability of filling the domestic productivity gap by domestic innovators ϕ is 0.81, with a 95% credible interval of $[0.68, 0.87]$. Introducing these values in the steady state relationships, we get a steady state value of a, the domestic productivity variable, of 0.91, which can be interpreted as an indicator of the closeness to the technological frontier of Hungary.

The posterior mean of the parameter measuring the sensitivity of the interest rate premium with respect to the net foreign asset position is estimated to be significantly smaller than our prior, i.e. 0.01, which implies that there is a much lower sensitivity of the interest rate premium to the level of external debt than assumed a priori. The value is about 0.003, with a credible set of $[0.002, 0.005]$. This is larger than the small value calibration of 0.001 in Schmitt-Grohé and Uribe (2003) that is frequently used in the literature. However, the estimation of DSGE models tends to obtain larger values for this parameter, see e.g. Adolfson et al. (2007) and "Real Business Cycles in Emerging Countries?" (2010), while empirical work such as Kónya and Maduko (2020) indicates that the estimated elasticity parameter is highly dependent on how developed the chosen country is and the time span covered by the data used in the estimation.

The estimation of χ, the parameter governing the magnitude of the wealth elasticity of labor supply, gives a posterior mean of 0.93 with a credible set of $[0.850, 0.995]$, which indicates that the utility function is practically defining KPR preferences. This implies that

[57] De Loecker and Warzynski (2012) adapted the method of Hall (1988) that was originally employed for the analysis of aggregate data to applications using micro data.

there is a strong income effect on labor supply, which Aguiar and Gopinath (2007) find to be in line with the stylized facts for transition economies.[58] There is a large array of estimates obtained in the literature that employ JR preferences, ranging from zero (Schmitt-Grohé and Uribe, 2012; Chang and Fernández, 2013) and thus supporting GHH preferences specification, through intermediate values indicating mild wealth effects (see e.g. Khan and Tsoukalas (2012) and Galí et al. (2012) for the result in the NK model without unemployment), to values close to one as in Siena (2021). However, to the best of our knowledge, there was no estimation of this parameter in a DSGE model with endogenous growth and hence we contribute to the literature with our finding.

The posterior means of the autocorrelation coefficients governing the stochastic processes of the structural shocks indicate that the most persistent disturbances are the domestic productivity shock and the shock to the share of BERD financed by the government. Both are in line in previous findings in the related literature. The estimate for ρ_{temp} is slightly above the standard value of 0.95 that is used for calibration in the RBC literature and usually obtained in DSGE model's estimations (see e.g. Smets and Wouters, 2003; 2007). The persistence coefficient for the shock to the share of BERD financed by the government is estimated to be 0.80. This is also a plausible result since government spending, in general, is often found to be a highly persistent process[59] and there is no reason to assume that the government spending directed to subsidize business R&D should behave differently. The other two domestic shocks, i.e. intertemporal preference and marginal efficiency of investment, have lower persistence coefficients. The relatively lower autocorrelation of these two shocks has emerged already in closed economy DSGE model estimations (Justiniano et al., 2011), but it is more prominent in small open economy setups (Gelain and Kulikov, 2011; Jakab and Kónya, 2016) since, as pointed out by Adolfson et al. (2007), the open economy aspects of the model are an additional source of frictions and disturbances. Nevertheless, the two shocks of foreign origin, the frontier technology growth shock and the MNCs' entry shock, are the least autocorrelated as they have the lowest estimated persistence coefficients.

Finally, the estimated standard deviations of shocks indicate that there are large differences in terms of volatility. The least volatile is the frontier technology growth shock, with a posterior mean standard error equal to 0.01. To the other extreme is the MNCs' entry shock that has the highest standard deviation (i.e. 0.32), which reflects the high volatility of inward FDI in Hungary.[60]

We compute all remaining parameters and steady state values of the endogenous variables in stationarized form to satisfy the steady state equations and shock our model with the structural shocks.[61] This allows to visually examine the dynamic effects of exogenous

[58] Aguiar and Gopinath (2007) show that the correlation between output and hours is much lower in EMs than in developed markets.

[59] This is the usual outcome of the Bayesian estimation of DSGE models, regardless of the data used and model setup. See, for example, Smets and Wouters (2003; 2007) Justiniano et al. (2010; 2011), or Gelain and Kulikov (2011), among others.

[60] These large differences in terms of estimated standard deviations of shocks is not unusual in DSGE model's estimations. See, for example, Justiniano et al. (2011) for a closed economy DSGE in which the MEI shock is highly volatile, and Adolfson et al. (2007) or Justiniano and Preston (2010), among others, for similar outcomes in estimated open economy models, where shocks related to terms of trade and exchange rates prove to be relatively more volatile.

[61] See Table 7 in Appendix C.5 for the values of all parameters.

shocks in a non-frontier economy, from which medium term frequencies can be examined in a relatively intuitive way as it follows in the next section.

5 Estimation Results

5.1 Model Fit

Even though the main purpose of this model is not to best fit the data,[62] we observe that it does a reasonable job in matching the actual volatilities of the observable variables. Table 2 reports the theoretical standard deviations of the observable variables generated by the model and their empirical counterparts. The model overestimates four volatilities and underestimates two of them, but half of the empirical standard deviations are contained in the 95% credible intervals generated by the model, while the other are marginally outside the bands.

Table 2: Comparison of Standard Deviations

	Model				**Data**
Variable	Mean	Median	5%	95%	
$\Delta \ln A^{aobs}$	1.881	1.841	1.404	2.271	2.042
$\Delta \ln Y^{qobs}$	1.378	1.370	1.207	1.545	0.945
$\Delta \ln C^{qobs}$	1.065	1.056	0.895	1.218	1.008
$\Delta \ln I^{qobs}$	4.018	3.900	3.075	4.963	2.913
g^{qobs}	1.065	1.053	0.883	1.237	0.602
Z^{aobs}	4.578	4.364	3.034	6.066	4.822

5.2 Variance Decomposition

As it can be observed in Table 3, the posterior mean variance decomposition of the observable variables to the various shocks of our model attributes a strong effect to the temporary productivity shock, which is usual in RBC models. The shock explains 70 percent of consumption growth, almost 50 percent of output growth and about 12 percent of investment growth. Among the other domestic shocks, the marginal efficiency of investment shock further explains about 78 percent of the variation in investment. It is followed by the intertemporal preference (discount factor) shock in a ranking of importance, the latter explaining about 23 percent of the variation in consumption and almost 19 percent of output's volatility.

An important finding is that the MNCs' entry shock has strongest effect on the observed measure of domestic productivity, explaining almost 97 percent of the variation in observed

[62] The introduction of nominal rigidities or trade may improve the fit of the model. However, in that case the estimation would be done with data for a sample period starting from 2001 due to both data availability and change in monetary policy, i.e. adoption of inflation targeting in Hungary.

Table 3: Posterior mean variance decomposition (in percent)

	u^g	u^f	u^{MEI}	u^{temp}	u^{beta}	u^{RD}
$\Delta \ln A^{aobs}$	2.98	96.54	0.02	0.44	0.01	0.02
	[0.89; 5.79]	[93.53; 98.79]	[0.00; 0.04]	[0.01; 0.82]	[0.00; 0.03]	[0.00; 0.06]
$\Delta \ln Y^{qobs}$	1.10	28.33	2.63	49.21	18.65	0.09
	[0.41; 2.08]	[17.41; 40.01]	[1.08; 4.45]	[37.35; 61.11]	[9.69; 28.05]	[0.00; 0.26]
$\Delta \ln C^{qobs}$	2.03	4.32	0.34	70.10	23.18	0.04
	[0.71; 3.84]	[0.46; 9.60]	[0.07; 0.74]	[55.56; 83.01]	[12.19; 35.55]	[0.00; 0.11]
$\Delta \ln I^{qobs}$	0.15	9.72	77.50	12.16	0.37	0.10
	[0.05; 0.30]	[3.13; 18.09]	[65.57; 88.46]	[5.59; 19.46]	[0.03; 0.99]	[0.00; 0.31]
g^{qobs}	100.00	0.00	0.00	0.00	0.00	0.00
	[100; 100]	[0.00; 0.00]	[0.00; 0.00]	[0.00; 0.00]	[0.00; 0.00]	[0.00; 0.00]
Z^{aobs}	0.00	0.00	0.00	0.00	0.00	100.00
	[0.00; 0.00]	[0.00; 0.00]	[0.00; 0.00]	[0.00; 0.00]	[0.00; 0.00]	[100; 100]

TFP. This shows how important FDI inflows are for domestic productivity and consequently for output of whose variation the MNCs' entry shock explains about 28 percent. Note that since MNCs' entry is endogenous, domestic shocks may also influence the decision of foreign companies to enter this country. However, the variance decomposition based on observed data indicates that over the period considered domestic factors did not play an important role in MNCs' entry decision given how little domestic shocks explain of TFP's volatility. This result is in line with various empirical studies that attribute the leading role in driving capital flow volatility to global factors (see, e.g., Kim (2000), Forbes and Warnock (2012), and references therein).

On what concerns the governmental subsidies, the R&D subsidy shock has almost no effect on the observed variables, which highlights the insignificant role played by this shock in driving domestic productivity or output growth.

5.3 Impulse Responses

We describe the general equilibrium effects of each shock in isolation, by studying the impulse response function (IRF) plots with the response of the endogenous variables, expressed in deviation from the steady state value, to a standard deviation change of the white noise disturbance for a horizon of 30 years (120 quarters).

One important observation from analyzing the impulse response functions obtained from our model is that temporary shocks can cast a long shadow on the economy. An interesting and very powerful shock, which is at the core of the contribution of this paper, is the positive shock ϵ_t^f to FDI flow into the country. As a response to this temporary shock, the set of sectors dominated by MNCs increases for a long time, as illustrated in Figure 6.

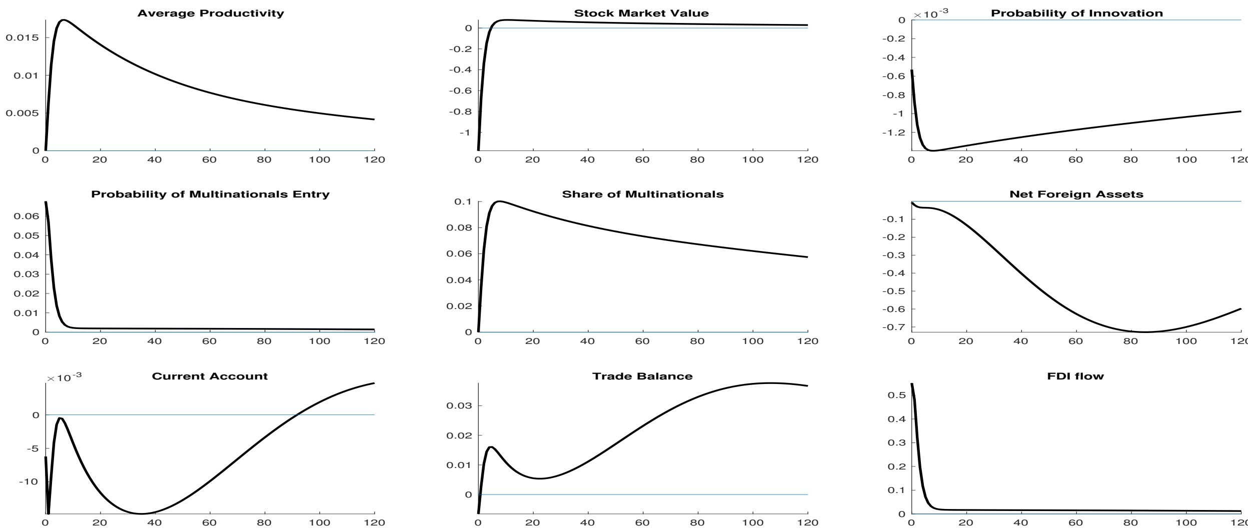

Figure 6: Impulse responses to a one estimated standard deviation MNCs probability of entry shock. The unit of the horizontal axis is quarters and of the vertical axis is deviations from steady state values.

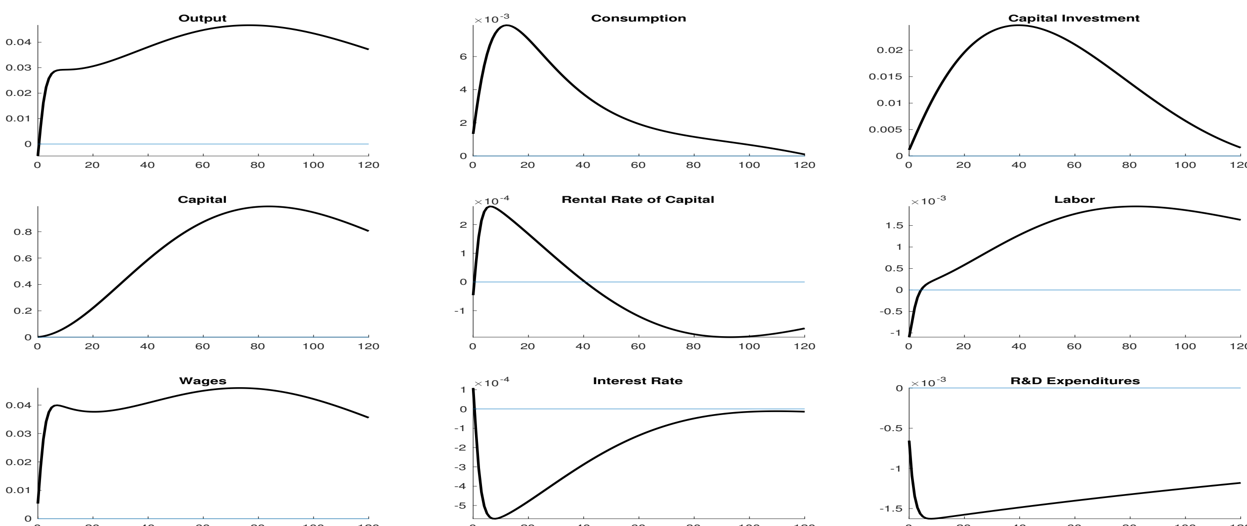

Figure 7: Impulse responses to a one estimated standard deviation MNCs probability of entry shock. The unit of the horizontal axis is quarters and of the vertical axis is deviations from steady state values.

The resulting increased flow of frontier technology into the domestic economy is reflected in the positive medium term effects on productivity, output, consumption, capital investment, and labor, with resulting dynamics displayed in Figures 6 and 7. Notice that this happens despite the drop in domestic R&D, discouraged by the increased probability of creative destruction for domestic innovators. This is also reflected in the initial drop of the stock market value of domestic firms. Hence, stronger MNCs' entry, while discouraging domestic innovation, brings about an overall growth process in the country lasting far longer than the initial shock. It is important to note that physical capital accumulation amplifies the medium-run effects on output and on workers wages, whose marginal productivity increases.

On the downside, we observe that MNCs' entry, by increasing the share of sectors dominated by multinational firms, implies that more dividends are repatriated by the owners of the foreign affiliates to their home country. This acts as a wealth shock that leads to a decline in the country's net foreign asset position. Households are poorer since they receive less dividends given that some of the companies they own became obsolete and thus need to adjust their consumption. This negative effect on consumption is the reason why the overall positive effect that we observe in the impulse response of consumption to the MNCs' entry shock is much smaller than in the one of output, both in the short and medium run. Since domestic demand for goods does not increase much, more output is thus available for trade, this leading to the improvement in the trade balance. The positive effect of the MNCs' entry shock on the trade balance is even stronger in the medium run when physical capital investment slows down.

The investment boom, the increase in dividend payments of MNCs, along with the decline in savings leads also to a a widening of the current account deficit. This confirms the findings of Calvo et al. (1996), who show that in the 1990s the largest recipients of capital inflows in Asia and Latin America also experienced larger current account deficits. Furthermore, using data for 58 DCs over the period 1978-1995, Bosworth et al. (1999) find that capital flows to DCs were in fact used to finance current account deficits and most of this resource transfer was directed into domestic investment and not consumption, which is in line with our results.

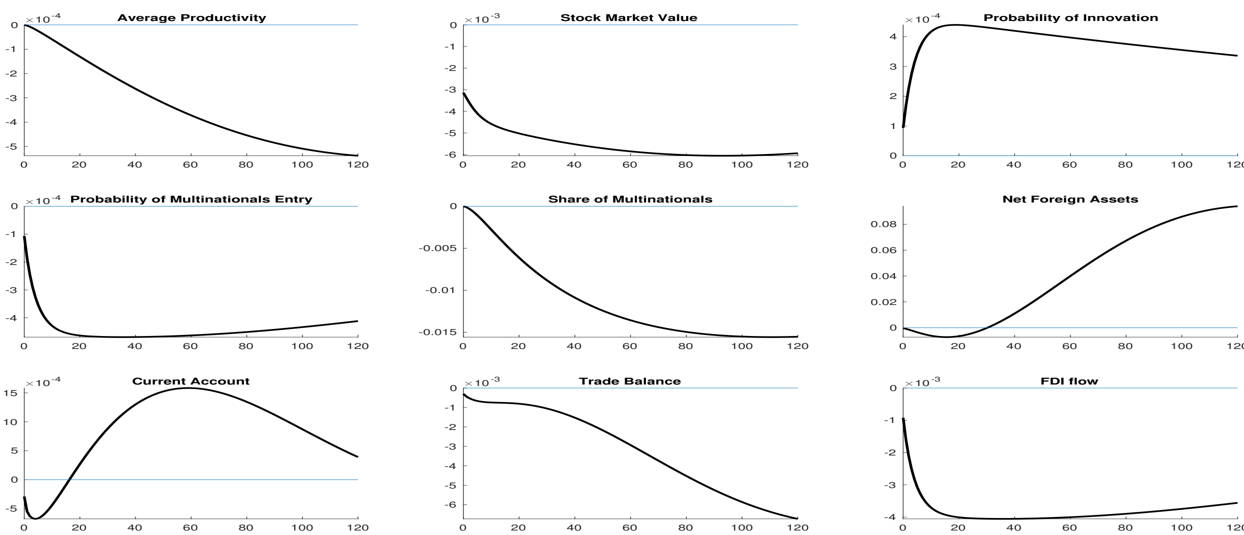

Figure 8: Impulse responses to a one estimated standard deviation R&D subsidy shock. The unit of the horizontal axis is quarters and of the vertical axis is deviations from steady state values.

Another valuable exercise is the analysis of the medium run response of the economy to an R&D subsidy shock. By introducing this shock in the model, we let the government temporary raise the share of the BERD investment that it finances and hence to tax more the representative household for this period. As displayed in Figures 8 and 9, the overall R&D investment increases, which leads to a higher probability of innovation. Unfortunately, this does not drive an increase in domestic productivity since MNCs' entry drops, discouraged by the policy action, and domestic R&D cannot compensate for the loss of their contribution to productivity growth. Therefore, through this channel in fact an R&D subsidy shock leads to a reduction instead of an increase in average productivity. Temporarily higher taxes and the decrease in the marginal product of capital leads to a drop in physical capital investment, which amplifies the negative effect of the decrease in endogenous productivity on output. However, households have more income coming from dividends payment since there is less foreign competition on the domestic market. This translates into an increase in consumption both in the short and medium run. Once the effect of the R&D subsidy shock fades away and the lump-sum tax on households returns to its previous level, savings increase and this is reflected in the medium run increase in net foreign assets. Nevertheless, all impulse responses indicate much smaller effects of the R&D subsidy shock in comparison with those of the MNCs' entry shock.

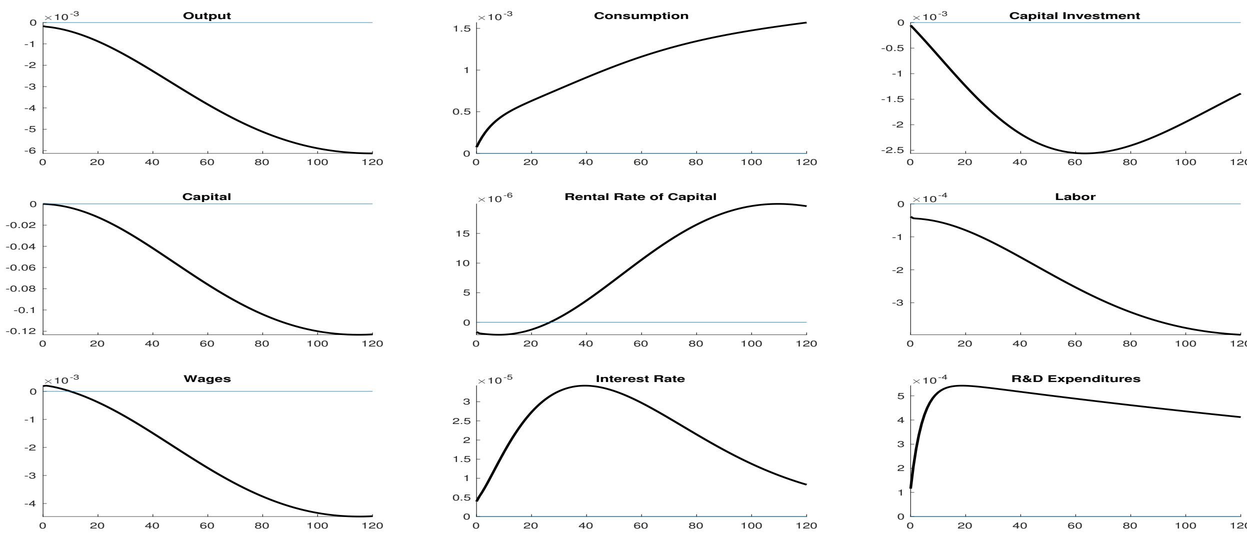

Figure 9: Impulse responses to a one estimated standard deviation R&D subsidy shock. The unit of the horizontal axis is quarters and of the vertical axis is deviations from steady state values.

5.4 Historical Shock Decomposition of Real Output Growth

In this section we quantify the contribution of exogenous shocks in explaining observed real GDP growth through the lens of the estimated model. In Figure 10 the continuous black line represents the observed quarterly real GDP growth rate over the period 1995:Q2 -2019Q4. The vertical bars indicate the contribution of the respective exogenous shocks to explaining the data in each period. Bars above the horizontal axis represent positive shock contributions, while bars below the axis indicate negative contributions.

Figure 10 illustrates the important role played by MNCs' entry shocks in driving the Hungarian GDP growth, especially before the Great Recession. The contributions of these shocks, marked as the light green bars, are in line with the periods of FDI policy identified by Antalóczy et al. (2011). This is an extremely valuable result given that we do not include data on FDI in our model estimation. According to Antalóczy et al. (2011), the first period started in 1988 and lasted until the mid 1990s, the second period lasted until the end of 2003, and the third period ended in the Great Recession of 2007-2009. We further consider that the fourth period began with the second premiership of Viktor Orbán in 2010 and was still ongoing at the end of 2019 when our sample period ended.

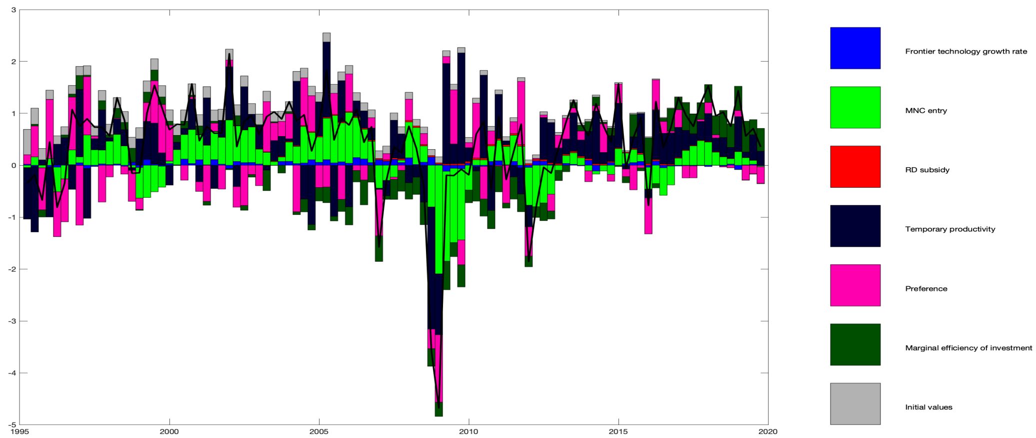

Figure 10: Historical shock decomposition of observed output growth. The continuous line represents the observed time series. Stacked vertical bars indicate the estimated contribution of different shocks in a given period. The contribution of all shocks recovers the observed variable.

While we do not have data for the first period, between 1988 and 1995, Hungary was not only one of the main recipients of foreign investment but also one step ahead the other CSEE countries in attracting privatization-related FDI for several reasons. First of all, the country had been experimenting with marketization since 1968 and was closer to a market economy than the other neighboring economies that started the transition in 1989. Moreover, the Hungarian government passed various laws that facilitated the selling of state enterprises to foreign investors earlier than the other countries in the region.[63]

By mid 1990s, the share of privatization-related FDI became negligible in Hungary since most state-owned companies had been already privatized, while the privatization process was taking off in the other Visegrád countries (Sass, 2004). This explains why at the beginning of the second period, between mid 1990s and 2000, which is also covered by our data, we observe in Figure 10 that the effect of the foreign firms' entry shock on Hungary's GDP growth is relatively small. However, according to Antalóczy et al. (2011), being a forerunner in terms of attracting privatization-related FDI gave a good signal to other potential foreign investors. At the same time, the more stable economic and political environment obtained in this second period in Hungary, along with various changes in the FDI policy, which became more transparent and normative, made Hungary a valuable destination for further FDI inflows. Hence, despite the regional competition for FDI coming from neighboring countries such as the Czech Republic or Slovakia, which introduced generous systems of incentives for foreign investors, Hungary continued to attract significant FDI inflows. In the period between 2000 and 2003, these inflows account for more than half of the positive contributions to Hungarian GDP growth, according to our estimates.

The third period started in 2004 due to the accession to the EU of most CSEE countries, including Hungary. In this period, the inflow of FDI in Hungary boosted because of the free movement of goods, services, capital, and labor implied by the EU Single Market. Moreover,

[63]See, e.g., Klaudt (1995), Antalóczy et al. (2011), and references therein, for more information on the post-revolutionary economic laws passed in Hungary and their implications for foreign investment.

the EU integration increased the confidence of foreign investors in the future economic development of the region and its political stability (Becker et al., 2010). Furthermore, having many of the countries in the region joining the EU at the same time implied a reduction in the regional incentive competition as they all had to change their FDI policies along the lines of the EU (Antalóczy et al., 2011). This is reflected in Figure 10 where we observe that after 2004 the MNCs' entry shocks contribute the most to Hungary's GDP growth (up to 1 percentage point in 2006Q1), acting as a catalyst of economic boom.

However, from the onset of the financial crisis in 2007, we observe the drawback of the openness to foreign investment through the exposure to international shocks, MNCs' entry having an immediate negative impact on Hungarian GDP growth. This may be attributed to the fact that the US is the largest non-EU investor in Hungary (U.S. Department of State, 2019). The negative effect of these foreign shocks has been the largest in 2008-2009 as the financial crisis spread globally and sparked the Great Recession, leading to a reduction in global foreign investment. Moreover, with several eurozone countries entering the European sovereign debt crisis by the end of 2009, investors feared further contagion of other European countries and flocked to safer investments. Our estimates indicate that negative MNCs' entry shocks depressed GDP growth by as much as 2.2 percentage points in 2009Q1, which amplified the economic downturn in Hungary.

In 2010 the parliamentary elections in Hungary led to the beginning of the second premiership of Viktor Orbán and a change in political attitude towards foreign presence. Therefore, we consider this to be the start of the fourth period in terms of FDI policies, which lasted at least until the end of our sample period, i.e. 2019Q4. In this period, FDI inflows increased in the CSEE region, but did not reach the pre-crisis levels. In Hungary, the shift from a democratic towards an authoritarian populist regime, increased corruption, the introduction of unpredictable industry-specific taxes and changes in regulatory policies favoring government-controlled companies, strong anti-migrant rhetoric and actions, have reduced foreign presence in various sectors and further discouraged MNCs' entry in general (Bershidsky, 2017; Ádám, 2019; U.S. Department of State, 2019; Eder, 2021). This explains the smaller contribution of MNCs' entry shocks after the Great Recession. However, the regulatory burdens aimed at decreasing foreign market share did not target foreign industrial investors, which in fact have continued to be lured in Hungary with special tax breaks and direct subsidies for large investments in the manufacturing sector, especially after 2016 (Benner and Reinicke, 2017; Sarnyai, 2018; U.S. Department of State, 2019; Eder, 2021). This coincides with the period in which we observe a persistent positive contribution of MNCs' entry shocks on Hungary's GDP growth, according to our estimates (see Figure 10). An important result of this analysis is the procyclicality of capital inflows in Hungary, which is in line with the findings of various empirical studies.[64] This is apparent in Figure 10, where positive contributions of MNCs' entry shocks are observed in boom periods, while negative contributions are mostly present in periods of recession.[65] Araujo et al. (2017a) point to the

[64]See, e.g., Kaminsky et al. (2004), Broner et al. (2013), Araujo et al. (2017a), and references therein, for empirical evidence in favor of the procyclicality of aggregate and disaggregate capital inflows based on data from a plethora of countries.

[65]Having foreign sources of fluctuations driving capital flows is supported by previous empirical research. For example, De Vita and Kyaw (2008) show that shocks to foreign output are among the most important forces explaining the variations in capital flows to DCs.

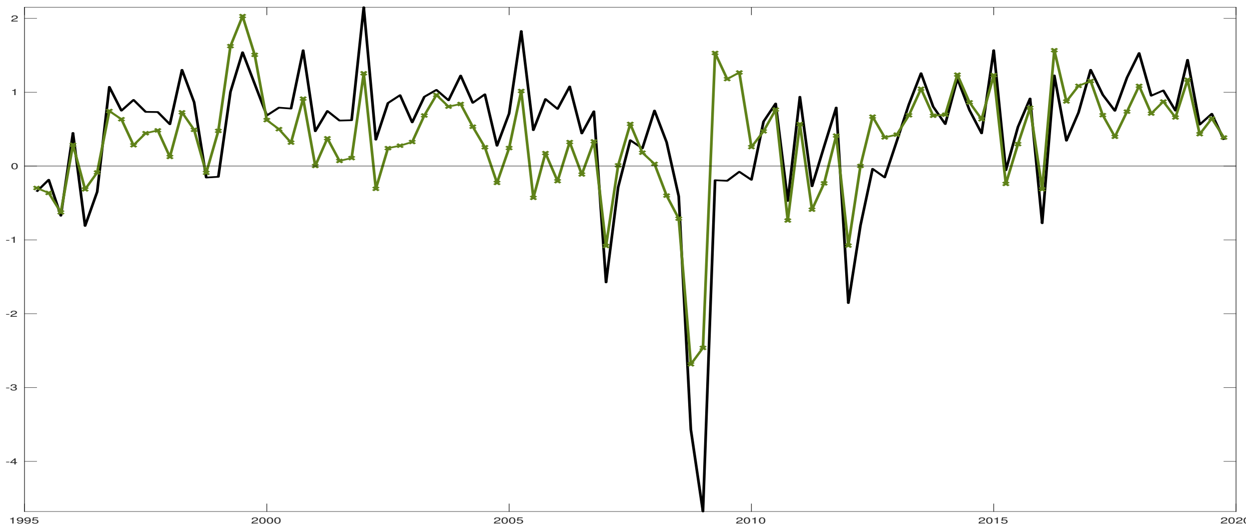

Figure 11: Comparison of observed output growth and the counterfactual obtained from the contribution of all shocks except MNCs' entry. The black line represents observed output growth. The green crossed line defines the counterfactual obtained from the estimated contribution of all shocks except MNCs' entry to the series.

dangers of procyclical capital inflows, in particular to the fact that they exacerbate macroeconomic fluctuations as well as amplify the domestic financial cycle. The empirical analysis of Kaminsky et al. (2004) further highlights that in DCs - and even more so in EMs - periods of capital inflows are associated with expansionary macroeconomic policies and periods of capital outflows with contractionary macroeconomic policies. Thus, macroeconomic policies in these countries mostly reinforce the business cycle, which is in stark contrast with the appropriate countercyclical measures that should be taken in order to stabilize the cycle. Valentinyi (2012) states that this has also been the case of Hungary, where the expansive fiscal policy and the build-up of a large external debt prior to the Great Recession made Hungary one of the most financially vulnerable countries in the CSEE. This is borne out in Figure 11, where we compare observed output growth and the counterfactual obtained from the contribution of all shocks except MNCs' entry.

Figure 11 shows that, in the absence of MNCs' entry shocks, economic fluctuations in Hungary would have been of lower magnitude over the period 1995Q2:2019Q4, with a coefficient of variation of 1.95 for the counterfactual series compared with a coefficient of 2.07 for the observed series. Our estimates indicate that MNCs' entry shocks not only make output more volatile but they have also dampened the recovery following both the global financial crisis and the sovereign debt crisis. The difference between the actual and the counterfactual series is most striking in the case of the financial crisis where we observe that, without the negative contribution of MNCs' entry shocks, output growth would have entered positive territory already in 2009Q2, while in reality this happened one year later. This is in line with the empirical findings of Milesi-Ferretti and Tille (2014), who show that capital flows to emerging Europe remained at a very low level in the recovery phase of the crisis, which is in stark contrast with Latin America and emerging Asia, where capital inflows quickly resumed after the crisis.

6 Concluding Remarks

In this paper we have introduced a Schumpeterian creative destruction model of the productivity dynamics of a generic non-frontier small open economy in a DSGE model. The integration of Schumpeterian growth and DSGE is not straightforward, but it opens the door to a more rigorous and complete analysis of medium frequency effects of shocks in non-frontier countries than previously achievable only by DSGE or Schumpeterian growth models taken in isolation.

We have used this model to study the interplay between MNCs entry and domestic R&D in driving endogenous productivity in a non-frontier economy and used Hungarian data for our quantitative application. According to our estimated model, MNC's entry proved to be both boon and bane for Hungary since on the one hand it impacted positively economic growth, while on the other hand it was a significant source of business cycle amplification between 1995 and 2019. On what concerns the government subsidies, the R&D subsidy shock had almost no effect on the observed variables, which highlights the insignificant role played by this shock in driving domestic productivity or output growth in both the short and medium run.

One of the main contributions of this paper is the extension of the business cycle model with endogenous technology to the case of non-frontier SOEs that undertake R&D to catch-up with the frontier but are at the same time exposed to MNCs' entry equipped with more advanced technology. Our estimation revealed that this is an empirically plausible model that can be used as a starting point to study the impact of MNCs entry on both the business cycle and the medium-to-long-term fluctuations in EMs.

Nevertheless, the proposed model purposefully abstracted from several important additional features that would increase the realism of the model and allow for more reliable estimation and policy evaluations, but that would also introduce complexity to a level that would render the exposition much less transparent. However, our setting could be extended in a relatively straightforward way in important directions. Most notably are two. One is the explicit introduction of a more complex government policy block with distortionary taxation, which would allow the simulation of government policies. Another is the introduction of nominal rigidities and trade, which would increase the realism of the model.

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A MNCs in the CSEE Region

As it can be observed in Table 4, foreign enterprises represent approximately three percent of the total number of firms in all groups. However, the share of foreign control in terms of either turnover, production value, or value added, is different between the groups. Regardless of the measure employed, foreign control is higher in the CSEE than in the EU15. The share of turnover under foreign control is about 38 percent in the CSEE, but slightly more than 30 percent in the EU15. The discrepancy is even higher when comparing the foreign penetration in terms of value added, but highest in terms of production value, the share for the CSEE being 8.6 percentage points higher.

When comparing the performance of foreign versus domestic enterprises in the three groups of countries based on productivity, we observe that labor productivity is larger in foreign firms than in their domestic counterparts regardless of the measure employed or the region considered.[66] The greatest disparity in labor productivity between foreign and domestic enterprises, using gross value added per person employed as a proxy, is registered in the CSEE region. However, when considering the wage adjusted labor productivity, measured as gross value added divided by personnel costs, the difference between the productivity in foreign-controlled and domestic firms is largest in the EU15. The reason for this could be the higher wages paid by foreign-controlled companies relative to those paid by the local firms, the gap being larger in the CSEE than in the EU15.

Table 4: MNCs at the level of 2014. Comparison of country groups

	CSEE	EU15	EU28
Foreign enterprises	3.1	3.0	2.9
Foreign penetration based on turnover	38.0	30.2	32.3
Foreign penetration based on production value	38.5	29.9	32.5
Foreign penetration based on value added	34.3	26.0	28.6
Relative apparent labor productivity	166.6	161.4	164.3
Relative wage adjusted labor productivity	117.7	121.9	120.0

The ratios for individual countries reported in Table 5 show that there is a wide variation within the CSEE region. Most foreign-controlled enterprises are registered in Latvia, 7.1 percent of the total number of companies, and Romania, 6.5 percent, while the least are in Poland, 0.5 percent of total, and Slovak Republic, 0.8 percent. Interestingly, foreign penetration in terms of either turnover, production value, or value added, in the countries with smaller shares of foreign-controlled enterprises is relatively high, which implies that fewer multinational companies generate a large turnover, production value, or value added. For example, in Poland these three foreign penetration indicators are close to 30 percent and are similar to the respective indicators for Slovenia where the number of foreign companies

[66]The labor productivity of domestic firms used in this analysis is in fact the labor productivity of all firms registered in the countries included in each group. However, as foreign firms represent a small share of the total number of firms, they may influence very little the average value of labor productivity. In any case, this would imply a small downward bias of the ratios reported.

represents 5.1 percent of the total. The highest penetration of foreign enterprises is observed in Hungary for which any of the indicators is above 50 percent even though the number of foreign enterprises in the economy is close to the CSEE average.

What is more important however is to compare the foreign penetration indicators used. Hunya (2017) shows that a direct comparison of these foreign penetration indicators provides important information concerning the activity of foreign affiliates in particular countries. For example, the author points to the fact that the Slovak Republic and Hungary have a similar share of foreign penetration in terms of production value, which is above 55 percent. Nevertheless, the indicator in terms of value added is more than 9 percentage points higher in Hungary than in the Slovak Republic. Hunya (2017) states that this in an indicator of the fact that the Slovak Republic is specialized in assembly work with a high imported content. In contrast, in the case of Poland the share of foreign penetration in terms of value added is higher than in production which makes Poland a more diverse economy, with much domestic sourcing.

Table 5: MNCs at the level of 2014. Comparison of individual countries

	Bulgaria	Croatia	Czech Rep.	Estonia	Hungary	Latvia
Foreign enterprises	3.5	2.8	1.3	1.2	3.6	7.1
Foreign penetration based on turnover	33.9	29.0	46.7	26.9	52.8	39.3
Foreign penetration based on production value	38.7	28.1	48.4	29.9	57.4	29.1
Foreign penetration based on value added	33.0	24.9	42.3	26.4	52.7	31.1
Employees in foreign enterprises	18.2	:	33.4	23.7	29.9	19.2

	Lithuania	Poland	Romania	Slovakia	Slovenia	CSEE
Foreign enterprises - % of total	2.1	0.5	6.5	0.8	5.1	3.1
Foreign penetration based on turnover	32.5	29.6	48.1	49.9	29.1	38.0
Foreign penetration based on production value	34.3	27.9	47.3	55.3	26.6	38.5
Foreign penetration based on value added	26.5	29.1	43.9	43.4	24.1	34.3
Employees in foreign enterprises - % of total	6.3	:	27.5	:	:	:

Note that ":" stands for missing information.

Table 6: MNCs in Hungary as a Percentage of the Business Sector

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
Foreign enterprises	3.3	3.3	3.3	3.4	3.4	3.5	3.6	3.2	2.9	2.7	2.6	3.2
Foreign penetration based on turnover	50.1	51.7	51.6	53.1	53.3	53.1	52.8	53.2	51.4	49.9	48.8	51.7
Foreign penetration based on production value	52.8	53.6	54.9	57.1	57.5	57.1	57.4	58.4	57.8	56.3	54.6	56.1
Foreign penetration based on value added	47	49.1	49.3	51.9	51.7	52.2	52.7	52.5	51.4	50	47.6	50.5
Employees in foreign enterprises	27.1	27.7	28.4	29.8	29.7	29.9	29.9	29.5	29.3	29.8	30.1	29.2

B Competitive Equilibrium

The competitive equilibrium for this model is defined by a set of prices and allocations such that, taking the initial conditions and the stochastic processes for the exogenous variables as given, household's allocation satisfies the optimal choices defined by the first order conditions; firms' allocations maximize profits; all markets clear; and budget constraints hold with equality.

The small open economy we are analyzing is always growing at the trend growth rate of exogenous frontier technology. Therefore in order to solve the model in a way manageable to analyze medium frequencies, we need to stationarize the trending variables. We will denote both stationary and stationarized variables with lowercase letters. For example, domestic productivity A_t, which eventually grows at the trend rate of $A_t^{\max}$, is stationarized by dividing it by $A_t^{\max}$, obtaining $a_t = \frac{A_t}{A_t^{\max}}$. We proceed similarly for all variables asymptotically growing like A_t, most notably output, consumption, wage rate, investments, physical capital, foreign bonds, trade balance, etc. Finally, variables with no trend, such as the interest rate, the rental rate of capital, and the probability of innovation by incumbents or MNCs, etc. have not been further stationarized. In equations in which variables appear at different dates, it will be necessary to deflate stationarized past variables and inflate stationarized forward-looking variables by the trend growth rate. We further deflate the nominal variables using P_t as deflator as done in the equations derived from solving the household's problem, but given the normalization $P_t = 1$ this brings no further changes. With all this is mind, the reader can now easily interpret the meaning of the stationarized model equations listed below.

The growth rate of frontier technology is:

$$g_t = g_{\text{exo}} + \epsilon_t^g.$$

The law of motion of s_t can be written as:

$$s_t = \left[c_t \exp\left(-g_t\right)^{\frac{1-\chi}{\chi}} - hc_{t-1} \exp\left(-g_t\right)^{\frac{1}{\chi}}\right]^{\chi} s_{t-1}^{1-\chi}.$$

The Euler Equation is:

$$\lambda_t = \mathbb{E}_t \beta \lambda_{t+1} \exp\left(-g_{t+1}\right)^{\sigma} (1 + r_t).$$

The first order condition with respect to consumption is given by:

$$\begin{aligned}
\lambda_t = & \exp(\epsilon_t^{\text{beta}}) \left[c_t - hc_{t-1} \exp\left(-g_t\right) - \omega \theta^{-1} l_t^{\theta} s_t\right]^{-\sigma} \\
& - \beta h \mathbb{E}_t \exp(\epsilon_{t+1}^{\text{beta}}) \left[c_{t+1} \exp\left(g_{t+1}\right) - hc_t - \omega \theta^{-1} l_{t+1}^{\theta} s_{t+1} \exp\left(g_{t+1}\right)\right]^{-\sigma} \\
& - \pi_t \chi \left(c_t \exp\left(g_t\right) - hc_{t-1}\right)^{\chi-1} s_{t-1}^{1-\chi} + \beta h \chi \mathbb{E}_t \pi_{t+1} \exp\left(-g_{t+1}\right)^{\sigma} \left(c_{t+1} \exp\left(g_{t+1}\right) - hc_t\right)^{\chi-1} s_t^{1-\chi}.
\end{aligned}$$

The labor supply equation in stationarized form reads:

$$\exp(\epsilon_t^{\text{beta}}) \left[c_t - hc_{t-1} \exp\left(-g_t\right) - \omega \theta^{-1} l_t^{\theta} s_t\right]^{-\sigma} \omega (l_t)^{\theta-1} s_t = w_t \lambda_t.$$

The first order condition with respect to s_t is given by:

$$\begin{aligned}
\pi_t = & \exp(\epsilon_t^{\text{beta}}) \left[c_t - hc_{t-1} \exp\left(-g_t\right) - \omega \theta^{-1} l_t^{\theta} s_t\right]^{-\sigma} \omega \theta^{-1} l_{lt}^{\theta} \\
& + \beta (1-\chi) \mathbb{E}_t \pi_{t+1} \exp\left(-g_{t+1}\right)^{\sigma} \left(c_{t+1} \exp\left(g_{t+1}\right) - hc_t\right)^{\chi} s_t^{-\chi}.
\end{aligned}$$

The capital accumulation equation is:

$$k_t = \exp(\epsilon_t^{\text{MEI}}) i_t \left[1 - \eta_I \left(\frac{i_t}{i_{t-1}}\right)\right] + (1-\delta) k_{t-1} \exp\left(-g_t\right).$$

The price of capital equation becomes:

$$p_t^K \lambda_t = \mathbb{E}_t \beta \lambda_{t+1} \exp\left(-g_{t+1}\right) \left[r_{t+1}^K + p_{t+1}^K (1-\delta)\right],$$

while optimal investment choice now implies:

$$1 = \exp(\epsilon_t^{\text{MEI}}) p_t^K \left[1 - \frac{\gamma_K}{2}\left(\frac{i_t}{i_{t-1}} \exp\left(g_t\right) - exp\left(g_I\right)\right)^2 - \gamma_K \frac{i_t}{i_{t-1}} \exp\left(g_t\right) \left(\frac{i_t}{i_{t-1}} \exp\left(g_t\right) - exp\left(g_I\right)\right)\right].$$

Using the government's budget constraint we can solve for the lump sum taxes, $T_t = Z_t X_t$, which, along with the law of motion of net foreign assets and using the fact that real dividends received by the household are just the sum of real profits from intermediate good firms, we can replace in the budget constraint and obtain that

$$C_t + I_t + X_t + TB_t = Y_t,$$

i.e. the resource constraint of the economy. Its stationarized version is given by:

$$c_t + i_t + x_t + tb_t = y_t,$$

and the stationarized monopolistic dividends equation is:

$$d_t = y_t - r_t^K k_{t-1} \exp\left(-g_t\right) - w_t l_t.$$

We can also write the law of motion of net foreign assets as a stationarized equation:

$$b_t = (1 + r_{t-1}) b_{t-1} \exp\left(-g_t\right) - d_t F_t + tb_t.$$

The real interest rate on foreign assets or liabilities is

$$r_t = \bar{r} + \psi \left[\exp\left(\frac{\bar{b}}{\bar{y}} - \frac{b_t}{y_t}\right) - 1\right].$$

The current account in stationarized form is:

$$ca_t = tb_t - d_t F_t + r_{t-1} b_{t-1} \exp\left(-g_t\right).$$

The aggregate production function can be written in terms of stationarized variables as:

$$y_t = \exp\left(\epsilon_t^{\text{temp}}\right) \left(a_t\right)^{\alpha} \left(l_t\right)^{\alpha} \left[k_{t-1} \exp\left(-g_t\right)\right]^{1-\alpha}.$$

Moreover, the demand equation for capital is:

$$r_t^k = \frac{\xi - 1}{\xi}(1-\alpha)\frac{y_t}{k_{t-1}} \exp\left(g_t\right),$$

and for labor is:

$$w_t = \frac{\xi - 1}{\xi} \alpha \frac{y_t}{l_t}.$$

MNCs' entry probability function is stationarized as:

$$f_t = 1 - \exp\left(-\frac{m_t\left[1-\eta_f\left(\frac{m_t}{m_{t-1}}\right)\right]\exp(\epsilon_t^f)}{\varpi^f}\right),$$

where

$$\eta_f\left(\frac{m_t}{m_{t-1}}\right) = \frac{\gamma_f}{2}\left(\frac{m_t}{m_{t-1}}\exp\left(g_t\right) - exp\left(g_M\right)\right)^2.$$

The first order condition with respect to FDI is

$$p_t^{S\max}\exp\left(-\frac{m_t\left[1-\eta_f\left(\frac{m_t}{m_{t-1}}\right)\right]\exp(\epsilon_t^f)}{\varpi^f}\right)$$
$$\frac{\left[1-\eta_f\left(\frac{m_t}{m_{t-1}}\right)-\gamma_f\frac{m_t}{m_{t-1}}\left(\frac{m_t}{m_{t-1}}\exp\left(g_t\right)-\exp\left(g_M\right)\right)\right]\exp(\epsilon_t^f)}{\varpi^f} = R_{\mathrm{M}}.$$

Production function of innovation probability:

$$\frac{x_t\left[1-\eta_X\left(\frac{x_t}{x_{t-1}}\right)\right]}{\varpi^{RD}a_t^{\text{target}}} = \ln\left(\frac{1}{1-n_t}\right),$$

where

$$\eta_X\left(\frac{x_t}{x_{t-1}}\right) = \frac{\gamma_{RD}}{2}\left(\frac{x_t}{x_{t-1}}\exp\left(g_t\right) - exp\left(g_X\right)\right)^2.$$

R&D first order conditions:

$$\frac{x_t\left(1-\eta_X\left(\frac{x_t}{x_{t-1}}\right)\right)}{\varpi^{RD}a_t^{\text{target}}}$$
$$= \ln\left(\frac{p_t^S\left(1-f_t\right)\left[1-\eta_X\left(\frac{x_t}{x_{t-1}}\right)-\gamma_{RD}\exp\left(g_t\right)\frac{x_t}{x_{t-1}}\left(\frac{x_t}{x_{t-1}}\exp\left(g_t\right)-exp\left(g_X\right)\right)\right]}{\varpi^{RD}a_t^{\text{target}}\left(1-Z_t^{RD}\right)R_{\mathrm{RD}}}\right).$$

The average manufacturing firm value p^S in stationarized form is obtained from:

$$\lambda_t p_t^S = \mathbb{E}_t\beta\lambda_{t+1}\exp\left(g_{t+1}\right)^{1-\sigma}\left[d_{t+1} + p_{t+1}^S\left(1-n_{t+1}\right)\left(1-f_{t+1}\right)\right].$$

Frontier productivity-adjusted average target technology:

$$a_t^{\text{target}} = a_{t-1}\exp\left(-g_t\right) + \phi_{t-1}\left[1 - a_{t-1}\exp\left(-g_t\right)\right],$$

with ϕ_t defined by:

$$\phi_t = \phi_0^{(1-a_t)}.$$

Law of motion of domestic technology:

$$a_t = f_{t-1} + (1-f_{t-1})\left[n_{t-1}a_t^{\text{target}} + (1-n_{t-1})a_{t-1}\exp\left(-g_t\right)\right].$$

Firm values are proportional to their productivity index:

$$p_t^{S\max} = \frac{p_t^S}{a_t^{\text{target}}}.$$

Since all variables involved are stationary, the dynamics of the set of sectors dominated by MNCs remains the same:

$$F_t = F_{t-1} + (1 - F_{t-1})f_{t-1} - F_{t-1}(1 - f_{t-1})n_{t-1}.$$

Similarly, the following equations also remain unchanged:

$$\begin{aligned}
Z_t &= Z \exp(\epsilon_t^{RD}), \\
\epsilon_t^{\text{temp}} &= \rho_{\text{temp}}\epsilon_{t-1}^{\text{temp}} + u_t^{\text{temp}}, \\
\epsilon_t^{\text{beta}} &= \rho_{\text{beta}}\epsilon_{t-1}^{\text{beta}} + u_t^{\text{beta}}, \\
\epsilon_t^{MEI} &= \rho_{MEI}\epsilon_{t-1}^{MEI} + u_t^{MEI}, \\
\epsilon_t^{f} &= \rho_{f}\epsilon_{t-1}^{f} + u_t^{f}, \\
\epsilon_t^{g} &= \rho_{g}\epsilon_{t-1}^{g} + u_t^{g}, \text{ and} \\
\epsilon_t^{RD} &= \rho_{RD}\epsilon_{t-1}^{RD} + u_t^{RD}.
\end{aligned}$$

Therefore we have 28 independent equations for 28 endogenous variables: c_t, λ_t, r_t, l_t, w_t, y_t, a_t, a_t^{target}, k_t, r_t^K, i_t, p_t^K, d_t, n_t, p_t^S, $p_t^{S\max}$, x_t, b_t, tb_t, ca_t, F_t, m_t, ϕ_t, π_t, s_t, f_t, Z_t, g_t, plus six shocks with corresponding autoregressive processes ϵ_t^{MEI}, ϵ_t^{beta}, ϵ_t^{temp}, ϵ_t^{f}, ϵ_t^{g} and ϵ_t^{RD}.

The parameters are: σ, χ, ξ, α, g_{exo}, β, h, ω, θ, γ_K, δ, ν, γ_{RD}, ϖ^{RD}, R_{RD}, γ_f, ϖ^f, R_{M}, $\bar{r}$, $\bar{b}$, $\bar{y}$, ψ, Z, and the autocorrelation coefficients ρ_g, ρ_f, ρ_{temp}, ρ_{RD}, ρ_{beta}, ρ_{MEI}.

C Estimation

C.1 Identification

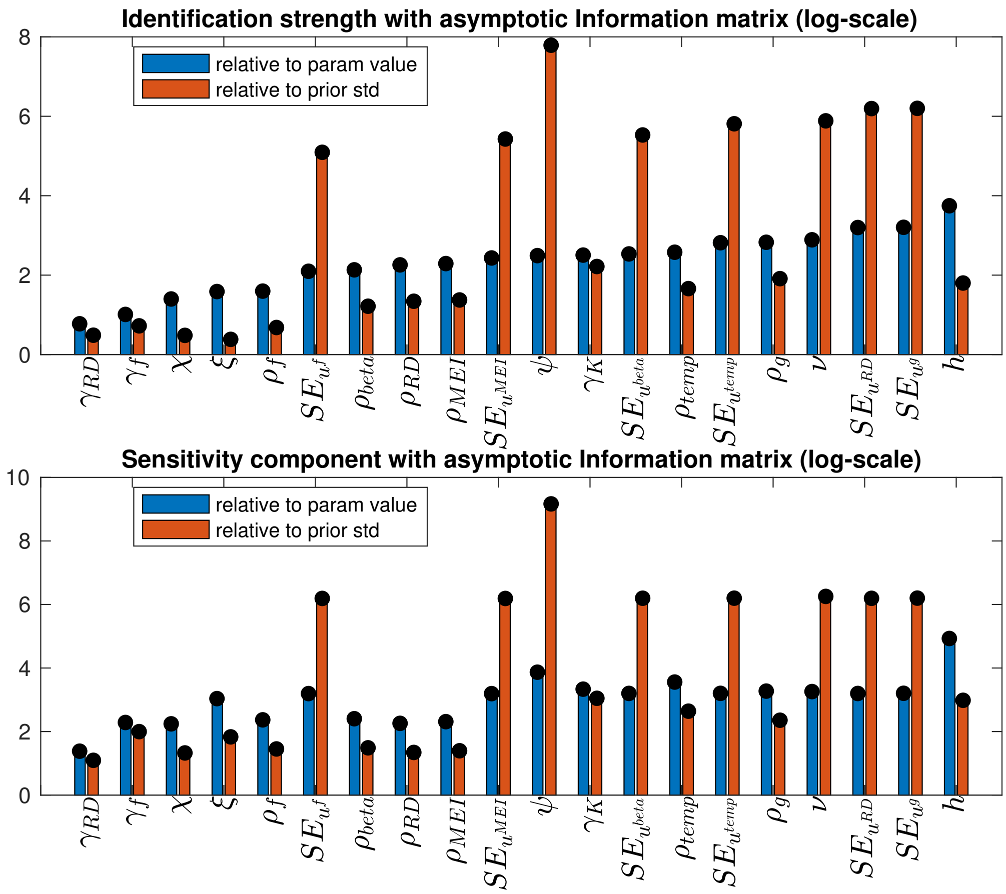

Figure 12: Prior mean - Identification using info from observables.

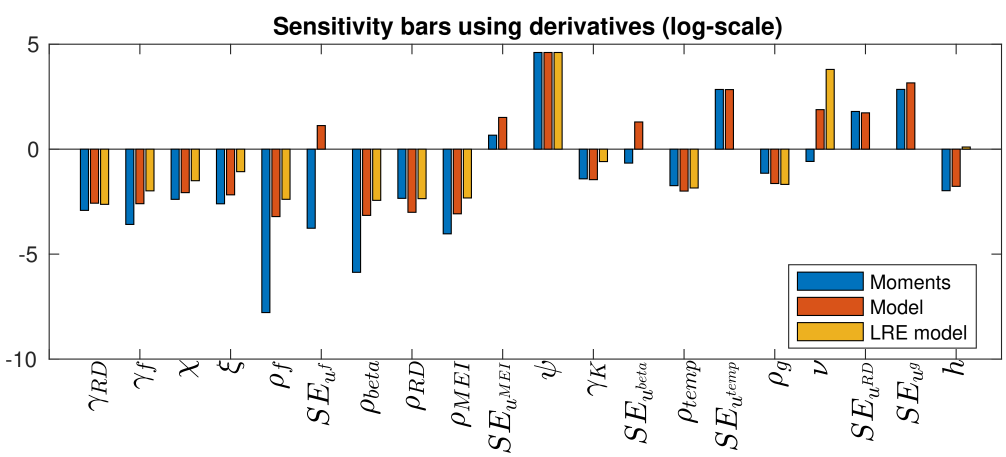

Figure 13: Prior mean - Sensitivity plot.

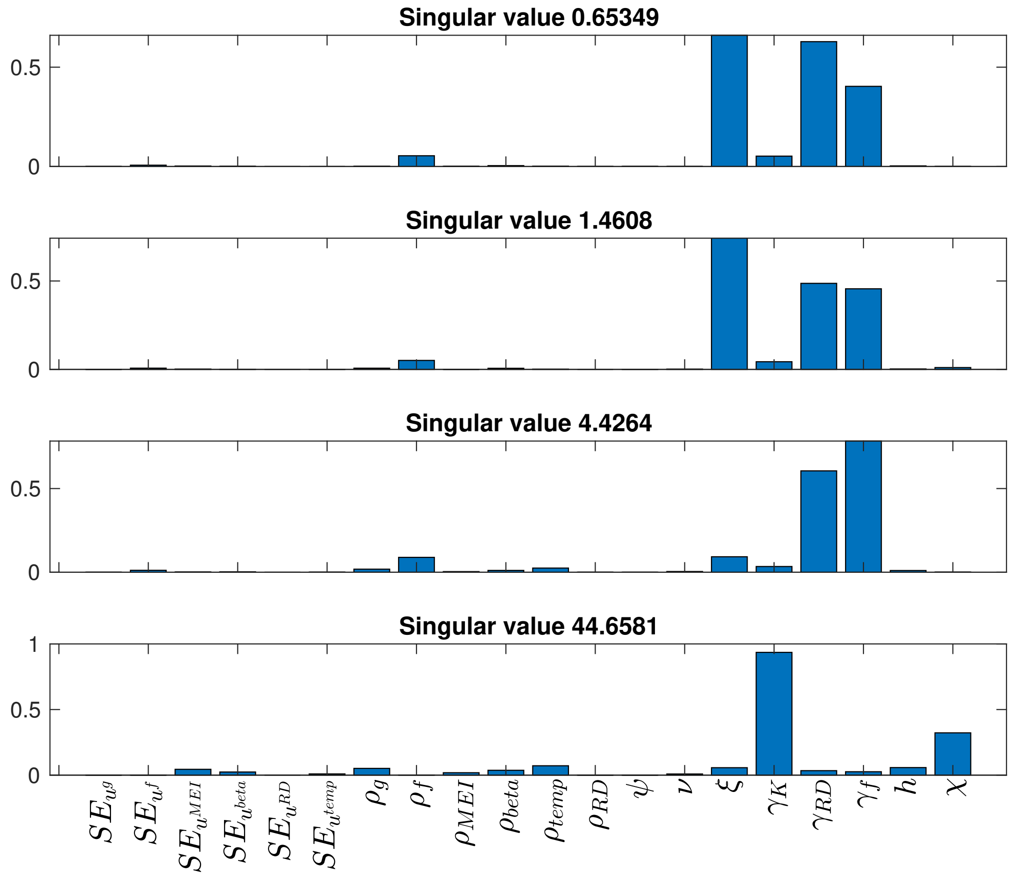

Figure 14: Prior mean - Identification patterns (Information matrix): SMALLEST SV.

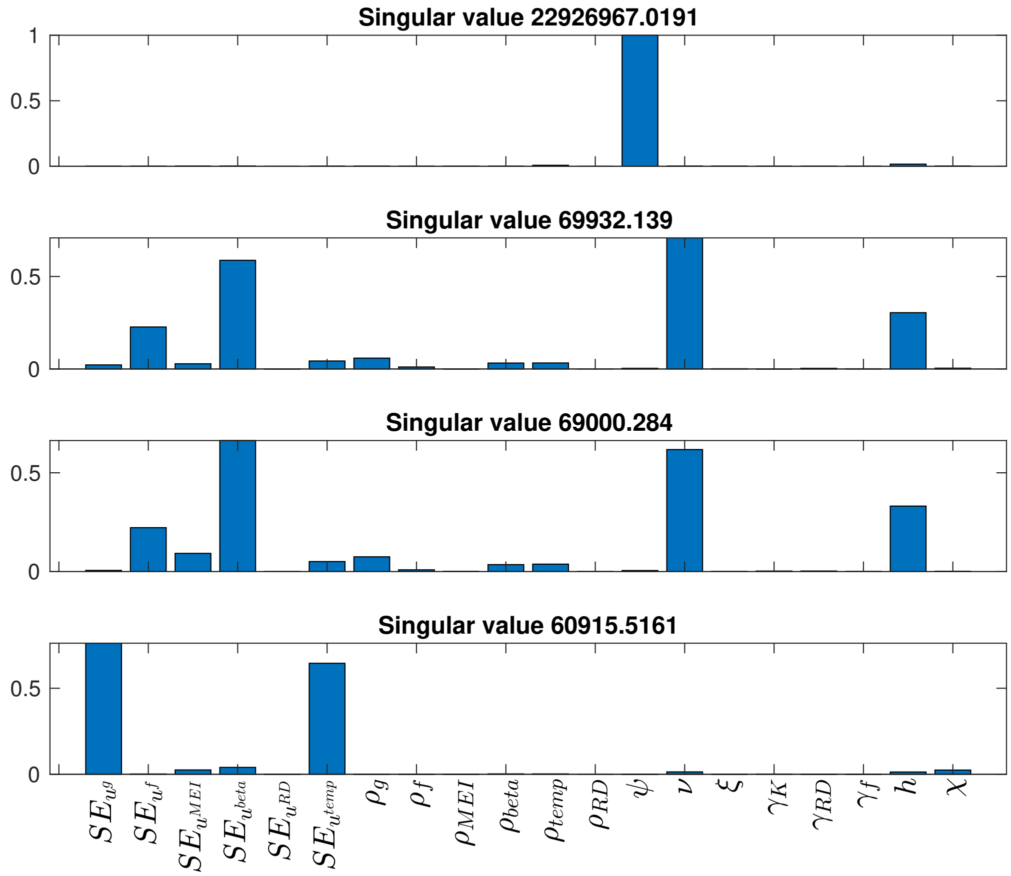

Figure 15: Prior mean - Identification patterns (Information matrix): HIGHEST SV.

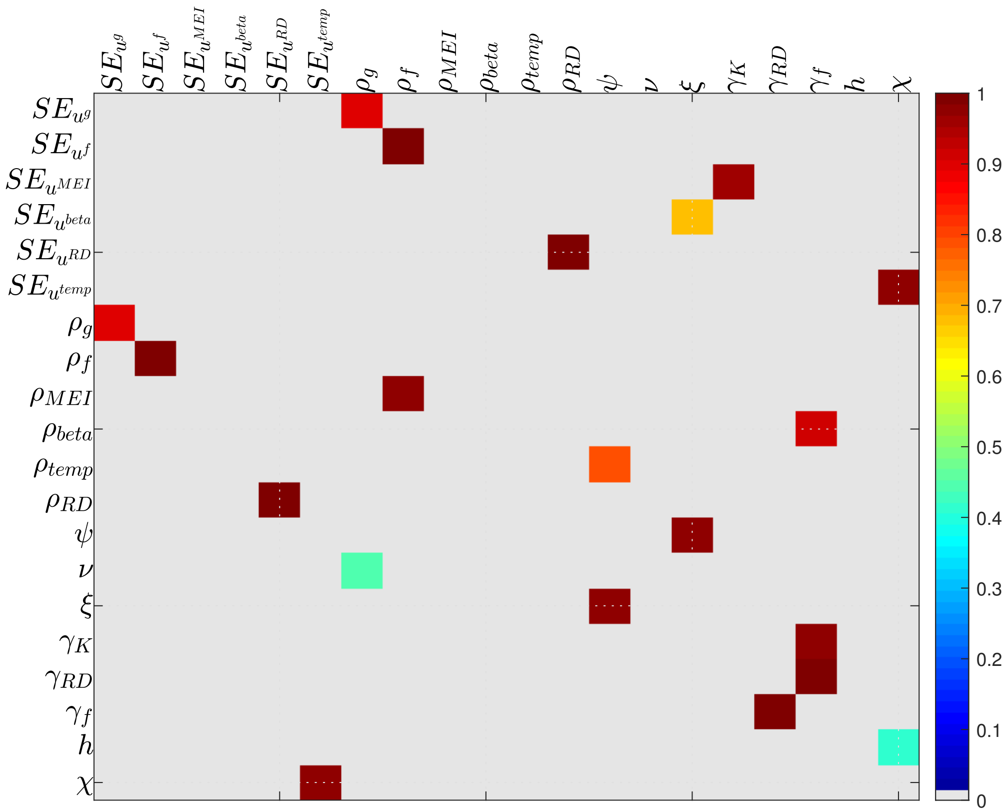

Figure 16: Prior mean - Collinearity patterns with 1 parameter(s).

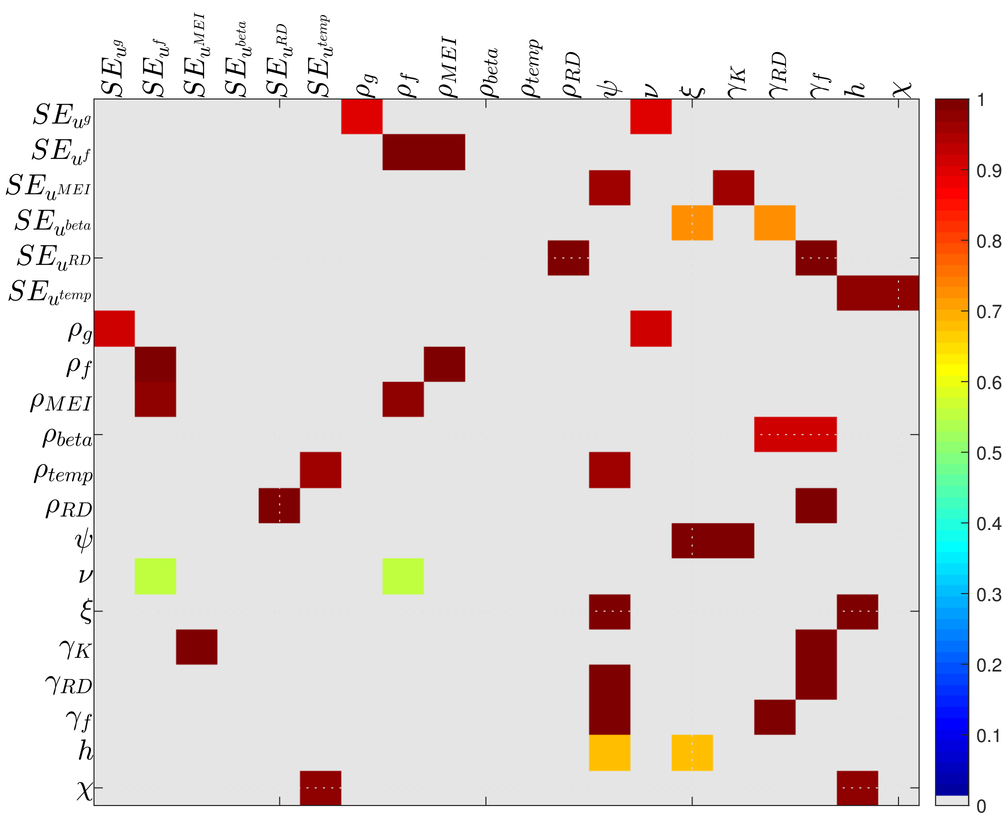

Figure 17: Prior mean - Collinearity patterns with 2 parameter(s).

C.2 Prior and Posterior Distribution

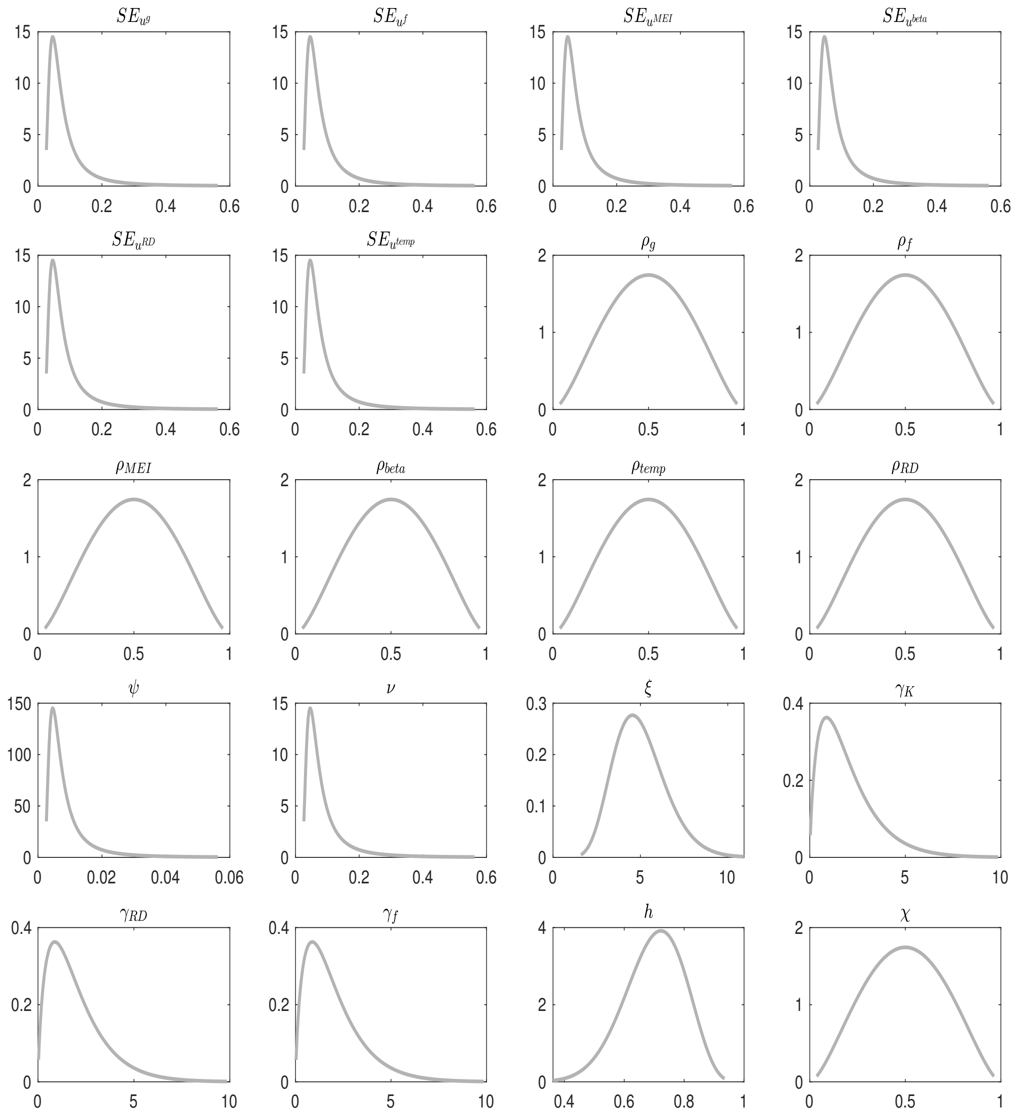

Figure 18: Prior distribution for the estimated parameters.

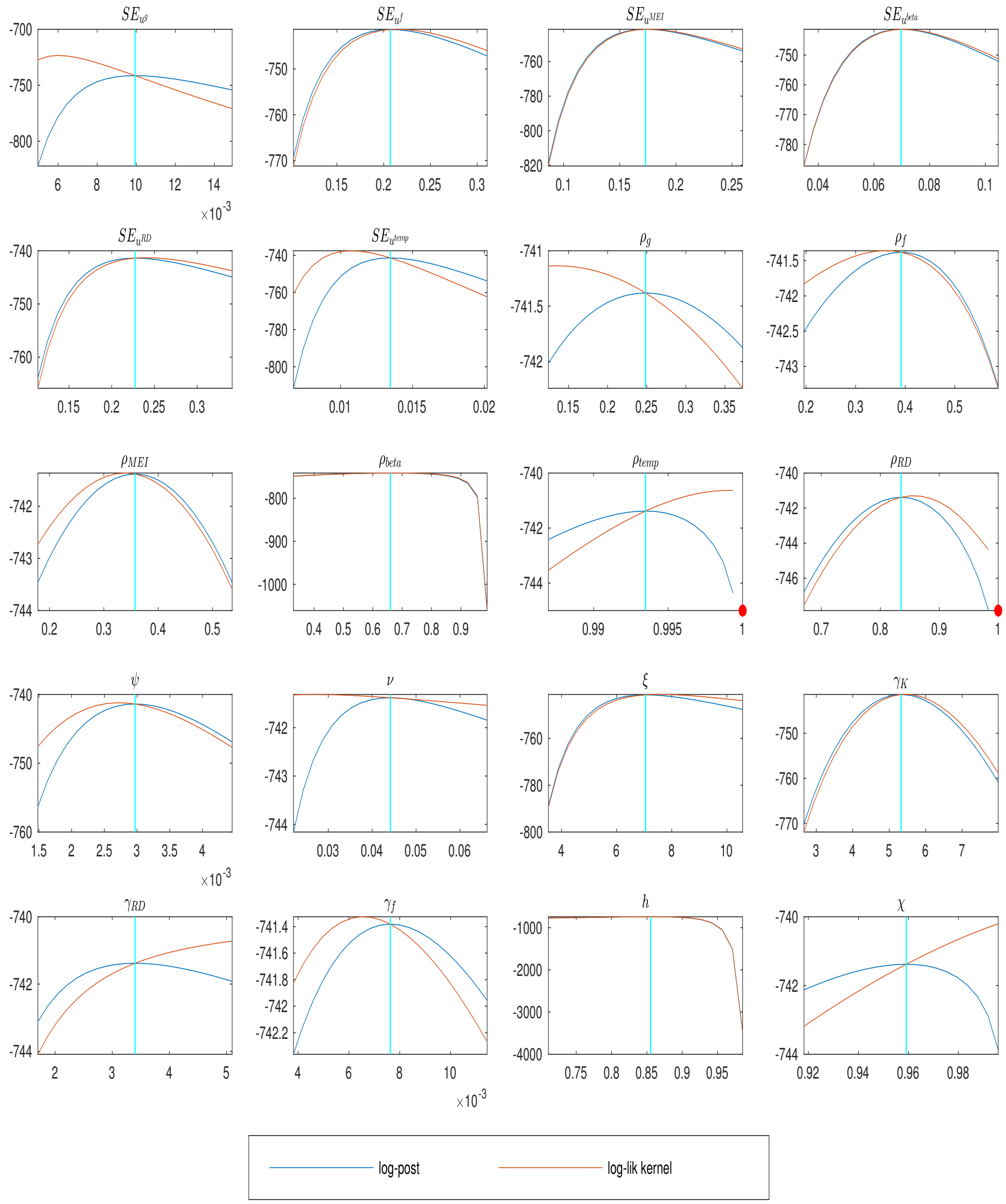

Figure 19: Posterior distribution for the estimated parameters.

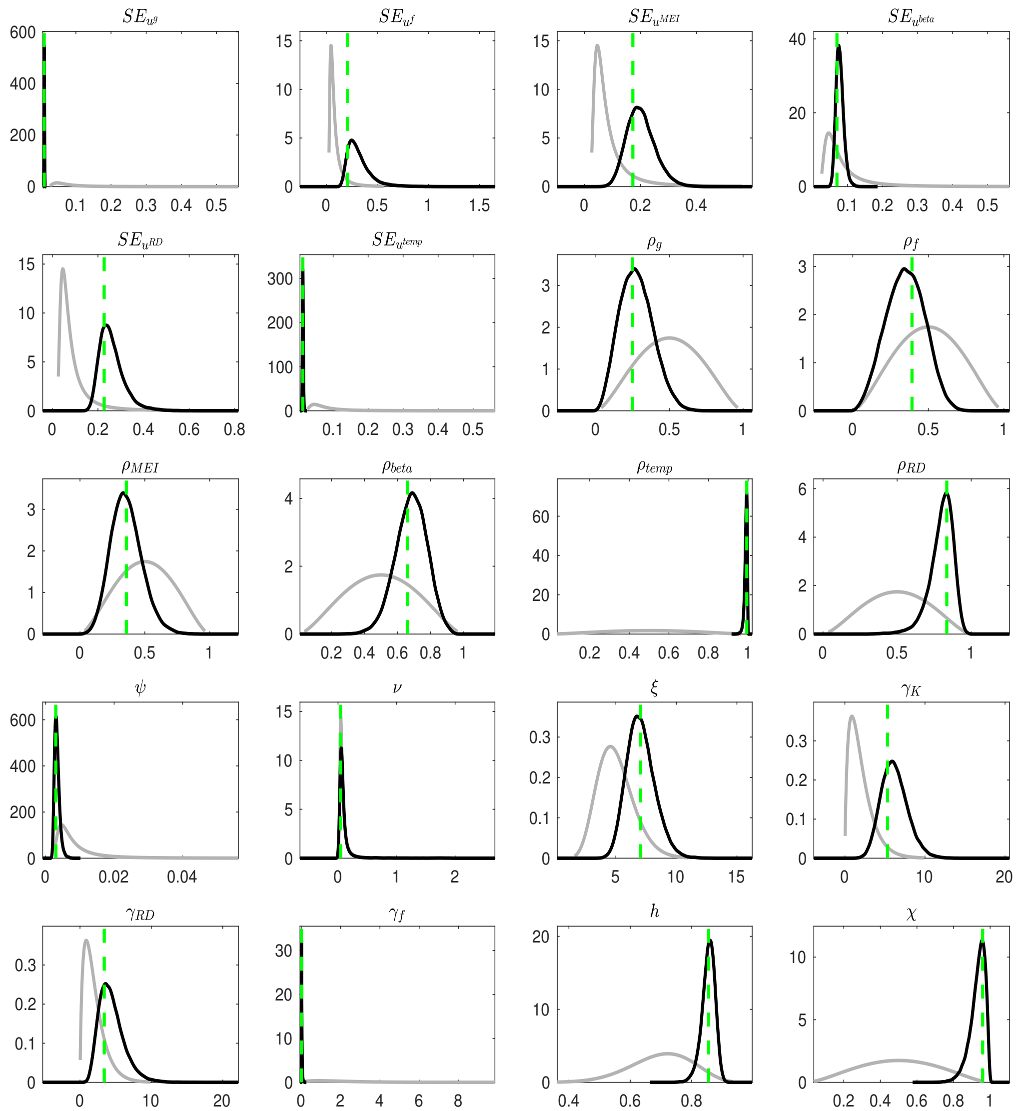

Figure 20: Priors and posteriors .The grey line defines the prior density, while the black line represents the density of the posterior distribution. The green horizontal line marks the posterior mode.

C.3 Convergence Checks

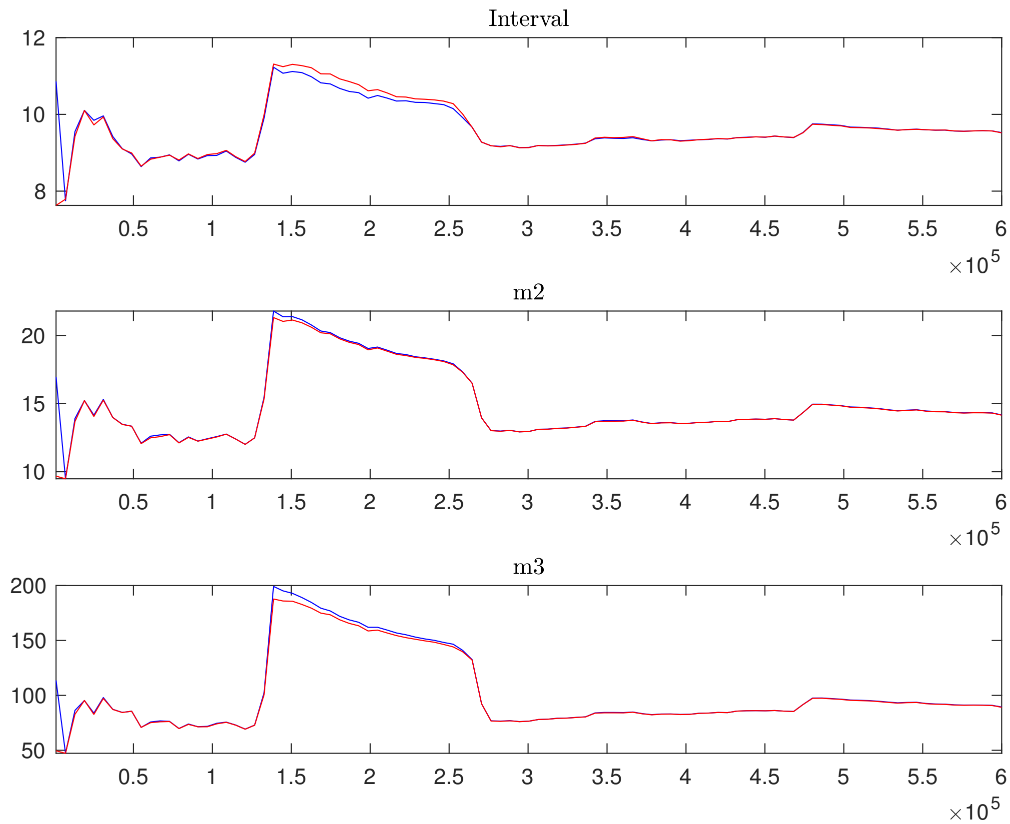

Figure 21: Multivariate convergence diagnostics for the Metropolis-Hastings. The first, second and third rows are respectively the criteria based on the eighty percent interval, the second and third moments. The different parameters are aggregated using the posterior kernel.

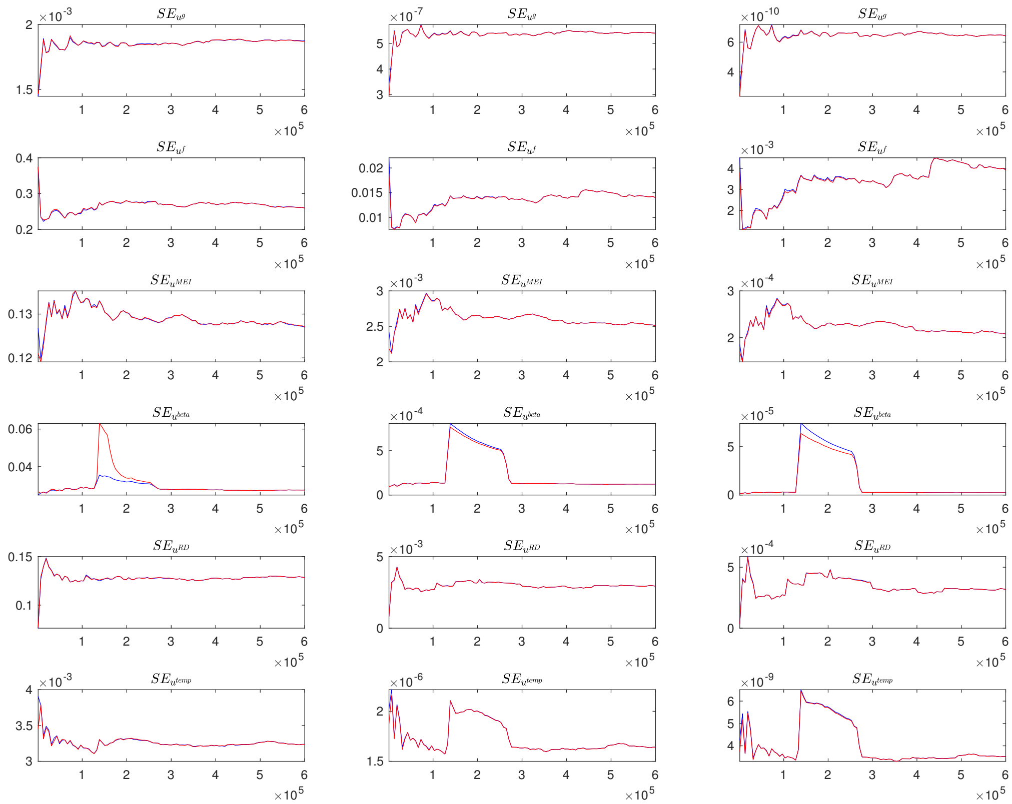

Figure 22: Univariate convergence diagnostics for the Metropolis-Hastings (standard deviations). The first, second and third columns are respectively the criteria based on the eighty percent interval, the second and third moments.

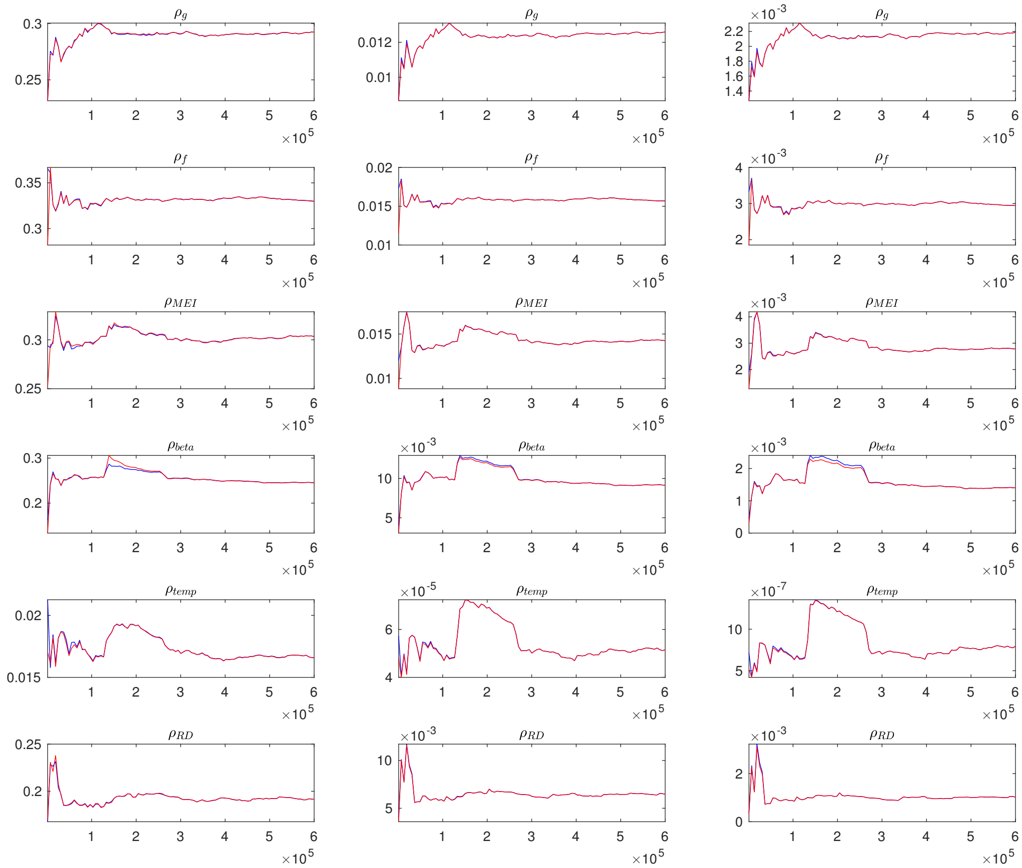

Figure 23: Univariate convergence diagnostics for the Metropolis-Hastings (autocorrelation coefficients). The first, second and third columns are respectively the criteria based on the eighty percent interval, the second and third moments.

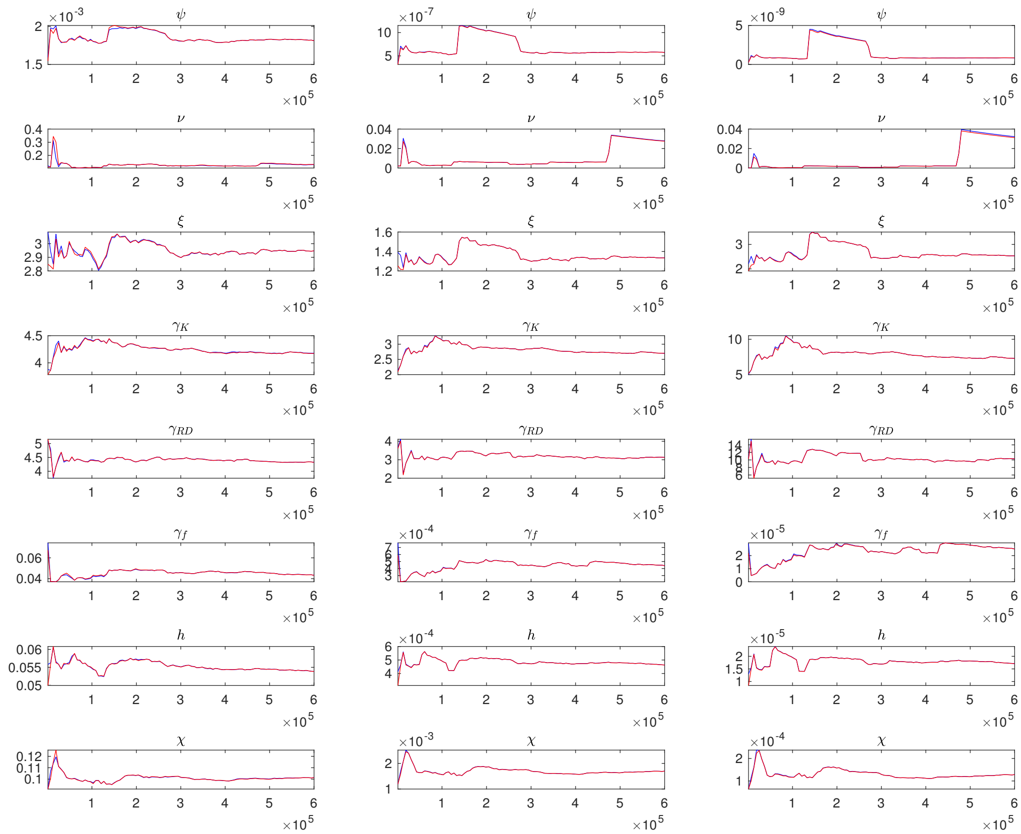

Figure 24: Univariate convergence diagnostics for the Metropolis-Hastings (model parameters). The first, second and third columns are respectively the criteria based on the eighty percent interval, the second and third moments.

C.4 Trace Plots

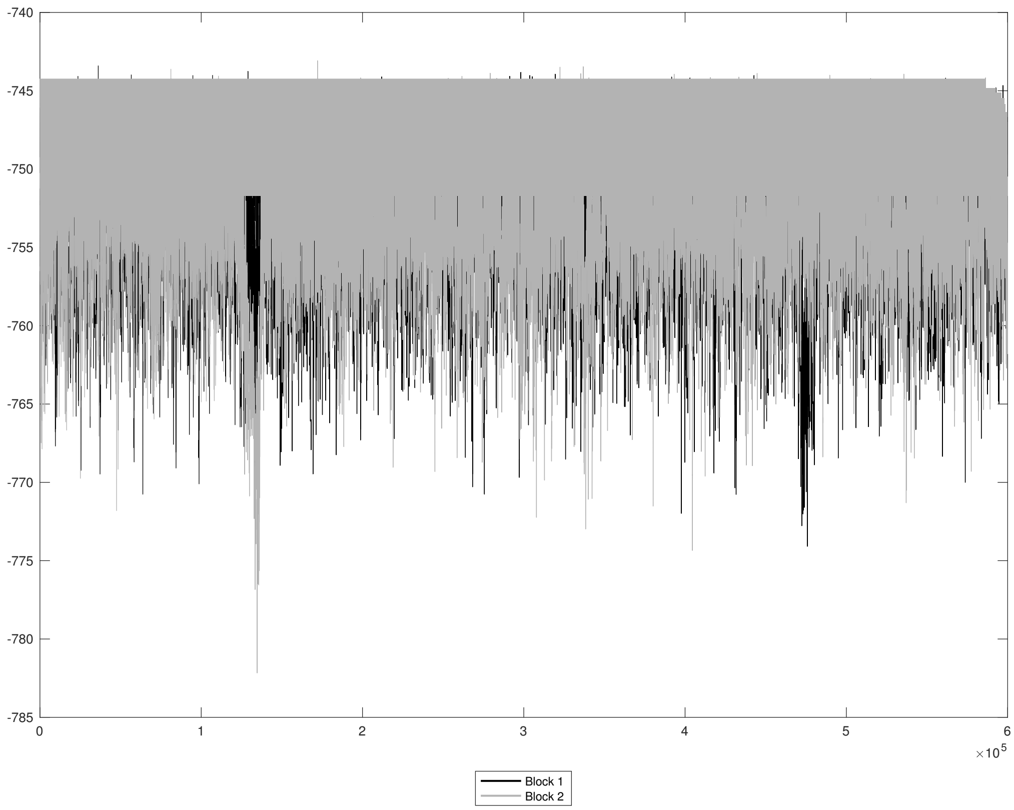

Figure 25: Trace plot for the posterior density

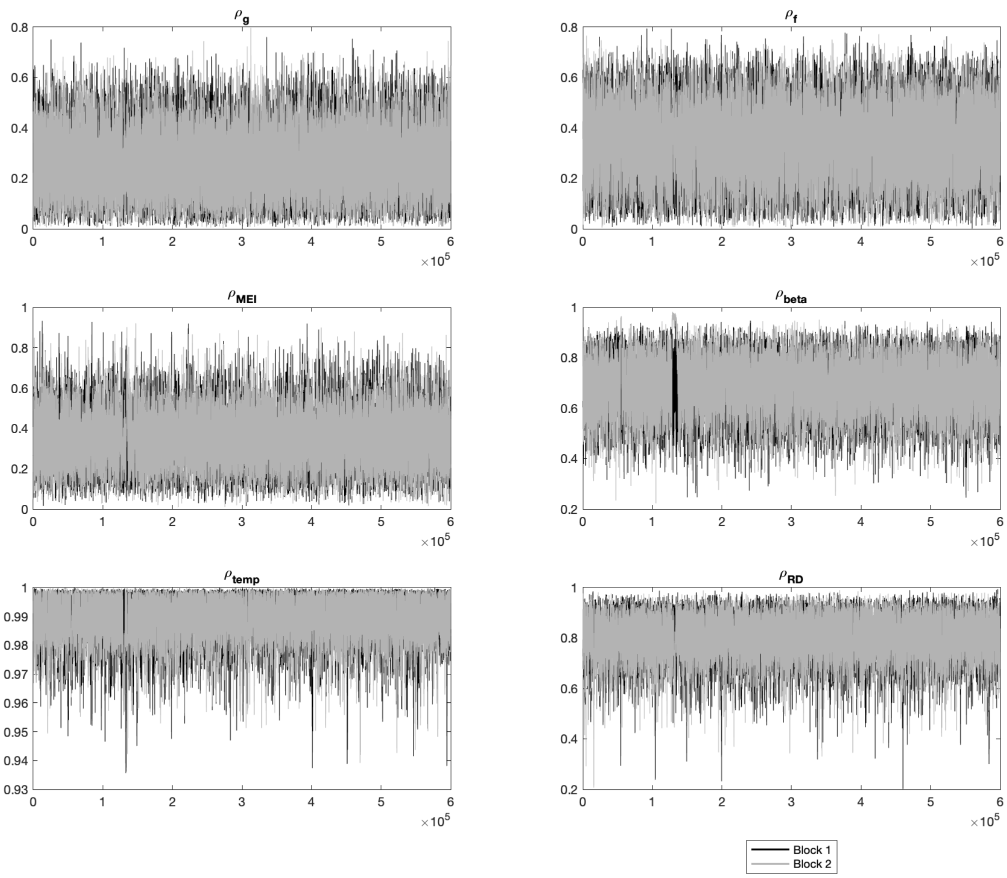

Figure 26: Trace plot for the autocorrelation coefficients

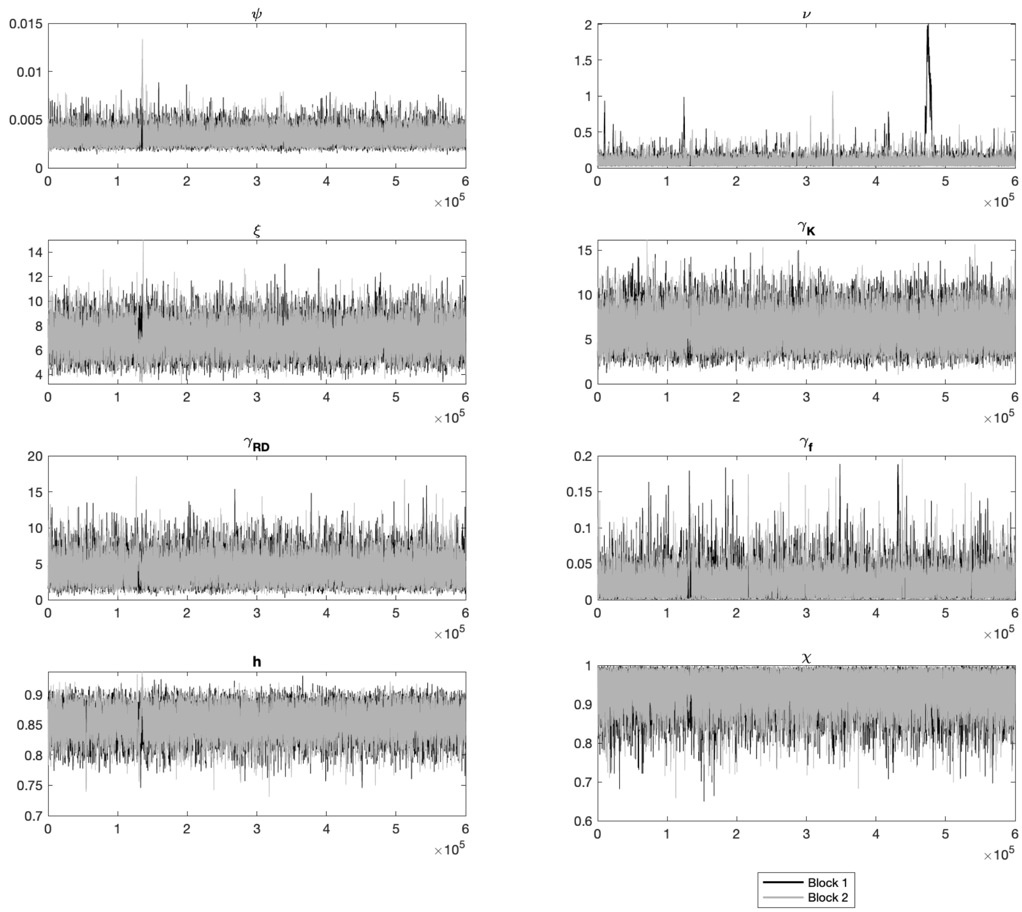

Figure 27: Trace plot for the model parameters

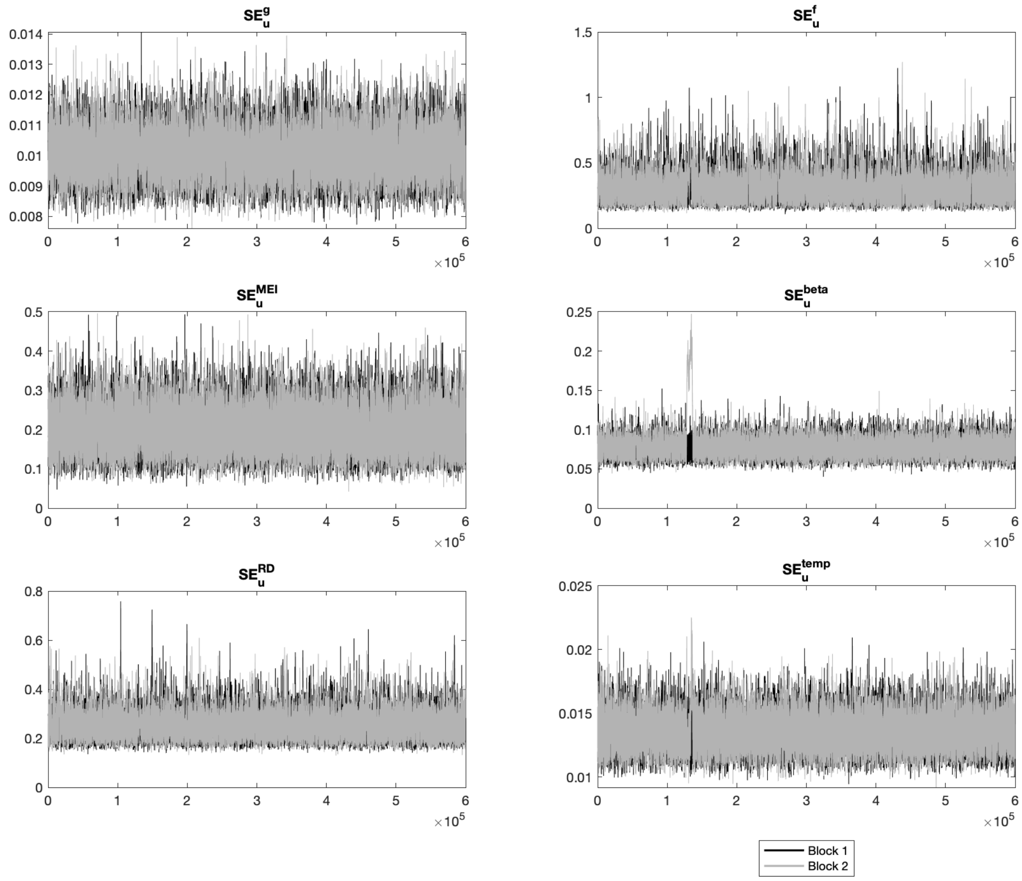

Figure 28: Trace plot for the standard deviation of structural shocks

C.5 Summary of Parameters

Table 7: Summary of Parameters

Parameter	Description	Value
	Calibrated Parameters	
α	Labor share	0.56
δ	Capital depreciation rate	0.01
β	Subjective discount factor	0.9875
g_{exo}	Steady state frontier technology growth rate	0.0023
$\bar{r}$	Steady state rest of the world interest rate	0.015
n	Steady state success probability of domestic innovation	0.0208
C/Y	Steady state consumption as a share of GDP	0.53
l	Steady state hours worked	1/3
θ	Parameter determining the elasticity of labor supply	2
σ	Parameter determining the intertemporal elasticity of substitution	2
F	Steady state share of MNCs in the economy	0.5
X/Y	Steady state BERD as a share of GDP	0.006
Z	Steady state government subsidy as a share of BERD	0.115
FDI/Y	Steady state FDI as a share of GDP	0.0415
	Estimated Parameters	
h	Internal consumption habit	0.855
χ	Parameter determining the size of the wealth effect	0.931
γ_K	Capital investment adjustment cost	6.165
γ_{RD}	R&D investment adjustment cost	4.414
γ_f	MNCs investment adjustment cost	0.025
ψ	Sensitivity parameter of the interest rate premium	0.003
ξ	Elasticity of substitution between intermediate goods	7.047
ν	Speed of productivity convergence	0.104
Autocorrelation Coefficients		
ρ^g	Shock to the frontier technology	0.275
ρ^{temp}	Temporary productivity shock	0.989
ρ^{beta}	Shock to household's preferences	0.681
ρ^{MEI}	Marginal efficiency to investment shock	0.357
ρ^{f}	MNCs' entry rate shock	0.347
ρ^{RD}	Shock to R&D subsidy	0.798
Standard Deviations		
$SE_{u^{\text{g}}}$	Shock to the frontier technology	0.010
$SE_{u^{\text{temp}}}$	Temporary productivity shock	0.014
$SE_{u^{\text{beta}}}$	Shock to household's preferences	0.078
$SE_{u^{\text{MEI}}}$	Marginal efficiency to investment shock	0.201
$SE_{u^{\text{f}}}$	MNCs' entry rate shock	0.318
$SE_{u^{\text{RD}}}$	Shock to R&D subsidy	0.260
	Endogenous Parameters	
ω	Labor disutility	5.890
ϖ^{RD}	R&D difficulty	1.241
R_{RD}	R&D fixed cost	8.781
ϖ^f	MNCs' entry difficulty	8.536
R_{M}	MNCs fixed entry cost	1.144

C.6 Other Estimation Results

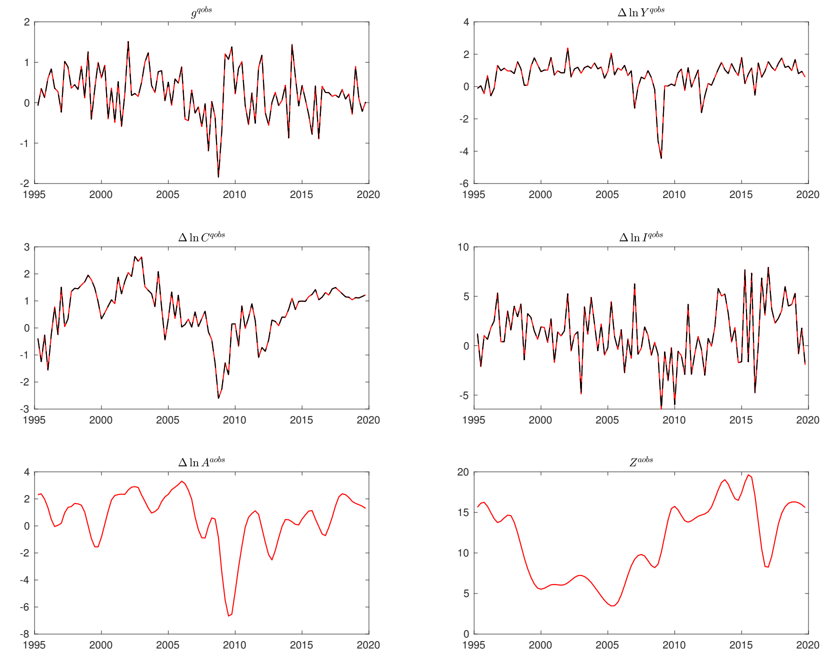

Figure 29: Historical and smoothed variables.

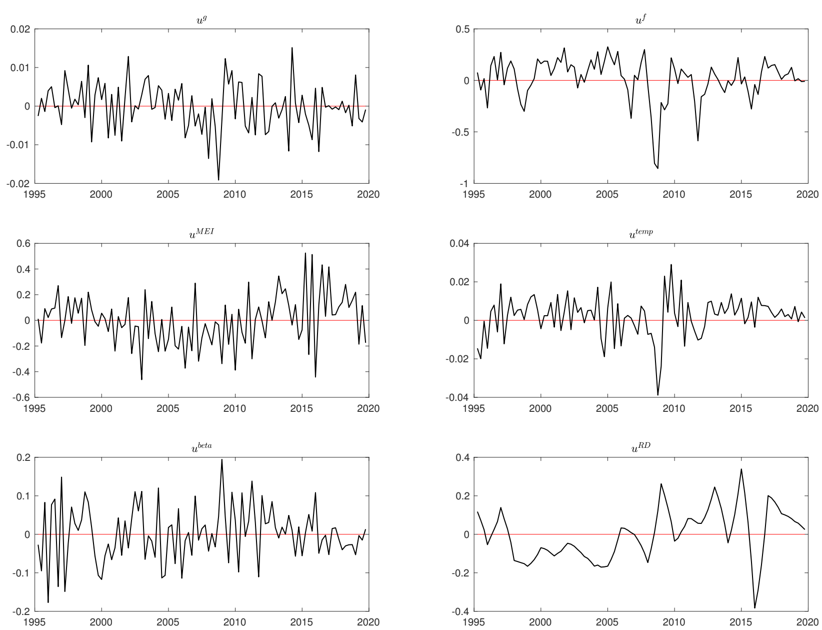

Figure 30: Smoothed shocks.