Multinational Firms and Business Cycle Transmission*

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Abstract

This paper studies the effect of foreign direct investment (FDI) on the transmission of international business cycles. In a sample of OECD countries between 1991 and 2006, I find that increases in bilateral FDI linkages are associated with more bilateral synchronization of real activity, in particular for aggregate investment. I then interpret these findings in a simple international real business cycle model of foreign direct investment. Multinational firms (i) transfer intangible technology capital to their foreign affiliates and are subject to (ii) multinational-specific productivity shocks, (iii) and produce goods that are used as inputs for other sectors. The calibrated model shows how the empirically observed changes in FDI integration can explain the increase in international business cycle synchronization measured in the data. The model suggests that the relation between FDI integration and international synchronization depends on the type of shock hitting the economy, on how intangible investments are measured in national accounts, and on how well international financial markets are integrated.

Keywords: FDI integration, Co-movement, Investment synchronization, Multinationals, Technology capital, International business cycles

JEL Classification Numbers: E32, F15, F21, F23, F44

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1 Introduction

Multinational firms account for a large share of global production; in 2010, multinational firms accounted for one-quarter of global GDP and about the same fraction of global gross fixed capital formation (UNCTAD, 2011). Multinational firms by definition own production facilities in multiple countries. They obtain these facilities by engaging in foreign direct investment (FDI), that is, the acquisition and control of foreign located capital and other production factors in countries other than the parent firm. A natural question is therefore how these cross-border linkages affect the international transmission of business cycles when countries become more integrated in terms of foreign direct investment. While there is growing empirical evidence at the firm, sectoral, and regional level that multinational activity is associated with more cross-country correlation,[1] it is an open question how FDI integration affects the international co-movement of important aggregate variables like Gross Domestic Product (GDP), its subcomponents, and employment. This paper aims to fill this gap by contributing to both the empirical and the theoretical debate on the effects of economic integration and aggregate synchronization.

Empirical contribution. The main empirical contribution is to document that increases in bilateral FDI linkages are associated with more investment synchronization. In the benchmark regressions, I use a panel data-set of bilateral FDI linkages and data on GDP and investment synchronization for 12 developed countries (including the G7) over the period 1991 - 2006. Exploiting the panel data structure of the data, I focus on changes over time within developed country-pairs.[2] The panel estimates assess how the evolution of business cycle synchronization is related to (de-facto) bilateral FDI integration within each country pair, conditional on global shocks, unobserved country-pair heterogeneity, and country-specific time trends. To the best of my knowledge, I am the first to investigate the relationship between within country-pair changes in bilateral FDI linkages and international synchronization of aggregate investment.[3]

I also document that the link between FDI linkages and output synchronization is positive but statistically indistinguishable from zero once controlling for common shocks and

[1] See Boehm, Flaaen, and Pandalai-Nayar (2015), Cravino and Levchenko (2016), Kleinert, Martin, and Toubal (2015).

[2] Kalemli-Ozcan, Papaioannou, and Peydró (2013) have shown the importance to control for common shocks and country-pair unobservable heterogeneity in the context of banking integration and business cycle synchronization.

[3] Desai, Foley, and Hines (2005) study whether foreign direct investments are complements or substitutes for domestic investment. They also show that domestic and foreign investment expenditures within U.S. multinational firms are substantially correlated. However, this literature is silent on the relation between FDI integration and international comovement of aggregate investment.

unobserved country-pair heterogeneity. This in confirms previous findings of Hsu, Wu, and Yau (2011) who find mixed evidence on the relation between FDI flows and GDP co-movement, depending on the empirical specification.

These two findings are important for two reasons. First, investment is a large component of GDP, so to understand its behavior in response to international capital market integration has its own merit. Second, and more importantly, these findings give additional moments to evaluate potential underlying mechanisms. In particular, an increase in cross-country investment correlation following capital market integration stands in contrast to the risk sharing view of financial integration usually taken in standard international business cycle theory. According to this literature, when global financial markets integrate, resources should flow to the most productive country; this implies a strong tendency for negative investment co-movement.[4] While also other explanations such as more correlated shocks, trade integration, or sectoral specialization are consistent with more co-movement when markets integrate, the empirical findings are robust to controlling for these factors, which suggests that FDI linkages have a separate role for business cycle transmission.

With respect to the weakly positive relation between FDI linkages and GDP synchronization, one could argue that - on aggregate - effects of capital market integration are small. In fact, many models of international business cycles generate that GDP co-movement is relatively less insensitive to capital market integration than investment. As I will show in this paper, the response of output to capital market integration depends on many things, like the international financial market structure and the type of shock the economies are exposed to. Another possible interpretation is that GDP as constructed in national accounts does not correctly reflect actual aggregate output due to the presence of unmeasured intangible investments. In national accounts, intangible investments are largely expensed. There is a growing literature assessing the importance of unmeasured intangible investments on growth and measured TFP, see, among others, McGrattan and Prescott (2010), McGrattan and Prescott (2014), and Kapicka (2012). Building on this literature, the theory studied in this paper gives rise to a cyclical varying gap between (measured) GDP and actual output. Hence, the framework allows me to quantify whether this gap affects the empirical estimates when regressing GDP synchronization on FDI linkages.

The empirical findings are more broadly also related to a large literature on economic

[4] This literature does typically not distinguish FDI from other financial assets. It either does not consider it at all or views it as portfolio investment that can be used to hedge country-specific shocks, see for example Backus, Kehoe, and Kydland (1992, 1994); Baxter and Crucini (1995); Heathcote and Perri (2002).

integration, focusing on trade and financial integration while abstracting from foreign direct investments. Typically, the literature finds a positive effect of trade or financial integration on GDP synchronization (Imbs, 2004). On the other hand, recent findings by Kalemli-Ozcan, Papaioannou, and Peydró (2013) suggest that the link between banking integration and business cycle co-movement is negative.

Theoretical contribution. From a theoretical perspective, my contribution is to develop a stylized dynamic stochastic equilibrium model of foreign direct investment. The theory embeds features from the models studied in McGrattan and Prescott (2009) and Ramondo and Rappoport (2010) into a dynamic stochastic real business cycle framework. As in McGrattan and Prescott (2009), multinationals accumulate technology capital. Similar to Ramondo and Rappoport (2010), multinational firms produce non-tradable intermediate inputs to a final good sector that produces traded goods. In addition, multinational firms are subject to firm-specific stochastic productivity shocks and these shocks apply simultaneously to all production units the multinational operates, both within and across country borders.[5] By allowing for multinational-specific shocks, the multinationals itself act as a source of business cycles volatility - on top of affecting the propagation of country-specific shocks that originate in other sectors of the economy. In my analysis, I consider different model versions (with and without multinational-specific shocks) that help to disentangle the role played by each model ingredient for the link between FDI openness and business cycle co-movement.

The first objective of the model is to illustrate a concrete mechanism through which exogenous changes in FDI openness affect business cycle synchronization, in particular investment synchronization, and to study how this mechanism works both under shocks to country-specific aggregate productivity and shocks to multinational activity.

The second purpose of the model is to quantify the importance of technology capital and multinational-specific shocks in explaining the observed relation between FDI integration and international co-movement of GDP, its subcomponents, and employment. I find that the model is qualitatively consistent with the empirical relation between FDI integration and business cycle synchronization: the response of investment synchronization is positive and large while the effect on GDP and employment is much weaker. Quantitatively, the technology capital and multinational-specific shocks together explain roughly half of the empirical relation between FDI integration and investment synchronization, while the effect of more FDI openness on GDP synchronization is positive and close to zero. This

[5] This is similar to Cravino and Levchenko (2016) who also focus on horizontal FDI. In their setup, technology is an exogenous shock that is only partially transferred to foreign affiliates. They abstract from endogenous accumulation of physical and technology capital.

suggests that the empirical findings are qualitatively and quantitatively consistent with the hypothesis that exogenous changes to FDI integration have significant effects on business cycle synchronization.

The third purpose is to shed light on what is driving the weak link between FDI integration and GDP synchronization as found in the data. I find that the response of output depends on the type of shock hitting the economy and on the ability of households to trade financial assets across countries or not, that is, whether financial markets for households are complete or shut down. In addition, the simulations reveal that the FDI-GDP regressions in the data might lead to wrong conclusions. The reason is that there is a gap between GDP as constructed in national accounts data and actual aggregate output; this gap is fluctuating systematically so that cross country-correlations computed using GDP over-predict actual output correlations for country pairs with small FDI linkages and under-predict actual output co-movement for country-pairs with relatively large FDI linkages. In the benchmark model, both aggregate output and GDP increases with more FDI openness. The marginal effect of more FDI openness on GDP, however, is 50 percent lower than the actual marginal effect using the correct measure for value added.

Finally, I explore the model to assess the risk sharing implications when countries' FDI openness increases. Even under financial complete markets, FDI integration reduces the aggregate risk households are exposed to. This reduction is strongest in the model with country-specific shocks only. To relate this to the literature, this result extends partly Ramondo and Rappoport (2010) to a dynamic environment; they find that multinational production changes the aggregate risk of the economy even though capital markets are complete by affecting the production side of the economy.[6] The reason for this risk reducing effect is that both consumption and hours worked become less volatile when countries are more open to FDI. Shocks to multinational activity, on the other hand, mitigate the risk-reducing effect of more FDI because production in both countries is increasingly determined by shocks to multinationals.

The model is also related to a growing strand of literature that stresses the importance of intangible capital for economic outcomes, such as asset prices (Eisfeldt and Papanikolaou, 2013), managerial compensation (Lustig, Syverson, and Van Nieuwerburgh, 2011), or the life-cycle of firms (Atkeson and Kehoe, 2005).[7] More closely related, Johri, Letendre, and Luo (2011) study the role of organizational capital for international investment co-movement and show that the stochastic growth model with organizational capital better

[6]The different layers of production in their economy is very similar to the one considered here. They consider a static environment and abstract from investment in technology and physical capital.

[7]These studies focus on organizational capital only whereas I adopt the broader definition of technology capital by McGrattan and Prescott (2009) that includes Brands, R&D, and organizational capital.

matches the unconditional cross-country correlation of investment; their model, however, abstracts from multinational firms and foreign direct investment and is therefore not suited to study the transition to FDI openness.

The paper is organized as follows. Section 2 reports the empirical methodology and the empirical results. Section 3 introduces the theoretical framework. Section 4 presents the quantitative results. Section **??** looks at the model implications for aggregate consumption risk and the quantity puzzle in international macroeconomics. Section 5 concludes.

2 Empirical results

2.1 Empirical specification

The empirical model is given by

$$synch^a_{i,j,t} = \theta_t + \gamma FDI_{i,j,t-1} + z'_{i,j,t}\beta + c_{i,j} + u_{i,j,t} \qquad \text{for} \qquad a = GDP, I. \tag{1}$$

where $synch^a_{i,j,t}$ is a time-varying bilateral measure reflecting the synchronization for growth in gross domestic product ($a = GDP$) and investment ($a = I$), respectively, between countries i and j in period (year) t. One period in the regression setup is one year. The variable $FDI_{i,j,t-1}$ measures bilateral cross-border FDI positions between country i and j in the previous period (year) and $c_{i,j}$ is a country-pair specific unobserved heterogeneity that captures all time-invariant bilateral factors that affect both FDI integration as well as business cycle and investment synchronization.[8] I also include time dummies (θ_t) to account for shocks common to all countries. Following Kalemli-Ozcan, Papaioannou, and Perri (2013), in order to separate the relative importance of global and country-specific shocks, I also report results for specifications where only country-specific time trends (g_i and g_j) and where both aggregate and country-specific time trends are included:

$$synch^a_{i,j,t} = \theta_t + (g_i + g_j) \cdot t + \gamma FDI_{i,j,t-1} + z'_{i,j,t}\beta + c_{i,j} + u_{i,j,t} \qquad \text{for} \qquad a = GDP, I.$$

The vector $z'_{i,j,t}$ contains measures for trade linkages and the product of the countries' income per capita and the countries' population. In addition, following the literature, I control for industrial specialization by taking the sum of each sectors' shares in total

[8] Other studies have stressed the importance of country-pair fixed effects, see Kalemli-Ozcan, Papaioannou, and Peydró (2013) and Kalemli-Ozcan, Papaioannou, and Perri (2013).

Table 1: Descriptive statistics

	N	Mean	Sd	Min	Max	p25	p50	p75	p95
G7 countries									
Pairwise corr. of GDP	336	0.373	0.434	-0.811	0.968	0.105	0.479	0.725	0.895
Pairwise corr. of Investm.	336	0.265	0.425	-0.848	0.969	-0.0418	0.297	0.607	0.883
Synch. of GDP	336	-2.317	1.192	-7.617	-0.332	-2.929	-2.076	-1.446	-0.872
Synch. of Investm.	336	-7.463	3.620	-25.12	-0.378	-9.335	-6.911	-4.845	-2.724
FDI/GDP	336	2.106	2.064	0.0729	11.45	0.504	1.524	3.147	6.449
FDI/total FDI	336	5.594	5.133	0.270	22.73	2.009	4.072	6.943	18.06
Trade/GDP	336	1.817	1.692	0.240	6.309	0.515	1.000	3.218	5.480
Trade/total trade	336	4.708	4.706	0.395	20.83	1.594	3.080	6.679	14.95
All country pairs									
Pairwise corr. of GDP	640	0.365	0.427	-0.811	0.968	0.0949	0.451	0.727	0.888
Pairwise corr. of Investm.	640	0.263	0.417	-0.848	0.969	-0.0326	0.302	0.583	0.881
Synch. of GDP	640	-2.501	1.427	-9.315	-0.187	-3.197	-2.129	-1.477	-0.898
Synch. of Investm.	640	-9.191	6.122	-42.54	-0.378	-11.13	-7.792	-5.090	-2.757
FDI/GDP	640	3.170	5.923	0.0466	54.70	0.475	1.492	3.491	10.77
FDI/total FDI	640	6.382	7.983	0.0762	50.92	1.400	4.072	8.050	19.14
Trade/GDP	640	1.721	1.749	0.0628	7.738	0.475	0.808	2.970	5.492
Trade/total trade	640	3.722	3.973	0.126	20.83	1.099	2.185	5.392	11.10

Notes: The table shows the descriptive statistics of the balanced sample for 40 country pairs from 1991 to 2006. The pairwise correlations of GDP and investment are the correlation of hp-filtered real GDP and hp-filtered real gross fixed capital formation, respectively. The GDP and investment synchronization indexes are defined in equations (2) and equation (3), respectively. The indexes are computed on a quarterly basis and then transformed into yearly observations by taking the average over four quarters. The synchronization indexes are in percent (annualized); FDI and trade ratios are defined in equations (4) and (5), the unit is percent. For a data description and a list of country pairs included in the sample see appendix A.

value added over all sectors.[9] All controls are lagged by one period to reduce the problem of potential endogeneity issues.

Following Kalemli-Ozcan, Papaioannou, and Perri (2013), I measure business cycle synchronization ($synch^{GDP}_{i,j,t}$) by the negative absolute distance in output growth rates between country i and country j in year t:

$$synch^{GDP}_{i,j,t} \equiv -\left|(\ln GDP_{i,t} - \ln GDP_{i,t-1}) - (\ln GDP_{j,t} - \ln GDP_{j,t-1})\right|. \qquad (2)$$

Analogously, cross-country investment synchronization in quarter t is defined as

$$synch^{I}_{i,j,t} \equiv -\left|(\ln I_{i,t} - \ln I_{i,t-1}) - (\ln I_{j,t} - \ln I_{j,t-1})\right|. \qquad (3)$$

As a robustness check, appendix B reports estimates where the dependent variables are cross-country correlations of hp-filtered investment and GDP, respectively.

I measure cross-border FDI linkages in two ways. First, I use the sum of bilateral asset

[9] See Imbs (2006).

and liabilities between countries i and j over the sum of the two countries' GDP in each year:[10]

$$\left(\frac{FDI}{GDP}\right)_{i,j,t} \equiv \frac{FDIA_{i,j,t} + FDIL_{i,j,t} + FDIA_{j,i,t} + FDIL_{j,i,t}}{GDP_{i,t} + GDP_{j,t}}. \quad (4)$$

Second, I use bilateral FDI assets and liabilities divided by the sum of total FDI assets and liabilities of the two countries:[11]

$$\left(\frac{FDI}{TotFDI}\right)_{i,j,t} \equiv \frac{FDIA_{i,j,t} + FDIL_{i,j,t} + FDIA_{j,i,t} + FDIL_{j,i,t}}{FDIA_{i,t} + FDIL_{i,t} + FDIA_{j,t} + FDIL_{j,t}}. \quad (5)$$

The sample for the empirical analysis in the main text consists of the 21 G7 country pairs for the years between 1991 and 2006. For a data description see Appendix A. The appendix also confirms the estimation results for a wider set of country pairs, using a balanced panel with 40 country pairs from 1991 to 2006.[12] Table 1 reports the descriptive statistics for the relevant variables in the sample.

2.2 FDI linkages and investment synchronization

This section reports the findings on the relation between FDI integration and international investment synchronization. Table 2 reports the benchmark estimates on the relation between FDI integration and investment synchronization for the G7 countries for the period 1991- 2006. The specification in column (1) controls for country-pair fixed effects and country specific time trends. The coefficient is positive and statistically different from zero. That is, conditional on country specific shocks, within country-pair increases in FDI integration are associated with more synchronized investment. In column (2), I include time fixed-effects to account for common global shocks, while column (3) reports results with time fixed-effects and country-specific time trends. In all specifications but specification (2), the coefficient on FDI integration is positive and statistically different from zero. In column (4), I control for bilateral trade linkages.[13] The coefficient on goods trade is positive and similar in magnitude as the coefficient on FDI integration. Yet we cannot reject the Null of a zero coefficient. Most importantly, when controlling for goods

[10]See Kalemli-Ozcan, Papaioannou, and Perri (2013).

[11]I also normalized bilateral FDI positions using total foreign assets and liabilities, finding similar results.

[12]The reason for using the restricted sample is data availability. For these country pairs there are no missing values for bilateral FDI positions and we have a balanced sample. Using the full (unbalanced) sample with 18 countries from 1985 to 2006 does not alter the main conclusions. Appendix B reports additional estimation results and robustness checks.

[13]Similar to FDI linkages, bilateral trade is defined as the log of the sum of bilateral trade flows divided by the sum of the countries' GDP.

Table 2: Bilateral FDI Linkages and Investment synchronization

Dependent Variable: Investment growth synchronization (annualized)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FDI/GDP	1.757**	1.486**	1.621**	1.549**				
	(2.67)	(2.21)	(2.70)	(2.46)				
Trade/GDP				1.370				
				(0.63)				
FDI/Total FDI					1.271*	1.567**	1.413**	1.320**
					(1.89)	(2.40)	(2.47)	(2.21)
Trade/Total Trade								1.412
								(0.75)
Country-pair fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Country trends	Yes	No	Yes	Yes	Yes	No	Yes	Yes
R-squared (within)	0.125	0.174	0.264	0.264	0.118	0.174	0.262	0.263
Observations	600	600	600	600	600	600	600	600

Notes: The table reports panel (country-pair) fixed-effect coefficients estimated over the period 1991 to 2006 for the 21 G7 country pairs. The dependent variable is minus one times the absolute value of the difference in quarterly growth rate of aggregate investment between country i and j in year t (the yearly estimate is obtained by averaging over the respective four quarterly estimates). In columns (1) - (4) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the previous year relative to the sum of the two countries' GDP in the previous year (denoted FDI/GDP). In columns (5) - (8) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the previous year relative to the sum of the two countries' total FDI Assets and FDI Liabilities in the entire world in the previous year (denoted FDI/Total FDI). All specifications also include the log of the two countries' per capita GDP, the log of the product of the two countries' population, and the log of the industrial specialization index as defined in the appendix; all controls are included with one period lag. The specification in (4) includes the log of the share of bilateral export and import flows between countries i and j in the previous year relative to the sum of the two countries' GDP in the previous year (Trade/GDP). The specification in (8) includes the log of the share of bilateral export and import flows between countries i and j in the previous year relative to the sum of the two countries' total exports and imports in the previous year (Trade/Total Trade). The specifications in columns (1) and (5) include country-specific linear time-trends. The specifications in columns (2) and (6) include time fixed-effects. The specifications in columns (3),(4),(7), and (8) include time fixed-effects and country-specific linear time-trends. Standard errors adjusted for panel (country-pair) specific auto-correlation and heteroskedasticity and corresponding t-statistics are reported below the point estimates. A † denotes significance at the 85% confidence level, * denotes significance at the 90% confidence level, ** denotes significance at the 95% confidence level, *** denotes significance at the 99% confidence level. For a detailed data description see appendix A.

trade does not affect the coefficient on FDI integration.[14]

To get a sense for the magnitudes, note that FDI linkages are expressed in logs and investment synchronization is in percentage points, hence the coefficients reflect semi-elasticities. The coefficient in column (3) implies that a doubling in bilateral integration (e.g., when moving from the 50 percent percentile to the 75 percent percentile of FDI linkages) is associated with an average increase in investment synchronization of 1.8 percentage points. Given the median investment synchronization is equal to -7.5 percent for the G7 countries these are economically large effects.

Columns (5) to (8) report the results using the alternative FDI integration index as defined in equation (5). The results are similar to the ones presented in columns (1) to (4). More FDI linkages are associated with higher investment synchronization; the point estimates are somewhat lower than the ones in specifications (1) to (4).

The estimated coefficients are robust to a number of robustness checks. In particular, using the full unbalanced sample for all available country pairs from 1985 to 2006, restricting the sample to the balanced sample of 40 country-pairs between 1991 - 2006, or using as a dependent variable the cross-country correlation of hp-filtered investment does not change the main results: higher FDI linkages are associated with more investment synchronization and the effect is economically large. Appendix B contains more details on these robustness checks.

2.3 FDI Linkages and GDP synchronization

In this section, I present the results of the benchmark estimations for the relation between integration and business cycle correlation. Table 3 reports the benchmark estimates on the effect of FDI linkages on GDP synchronization in the period 1991- 2006. In column (1), controlling for country-pair fixed effects and country specific time trends, the coefficient is positive and statistically different from zero. That is, conditional on country specific shocks, within country-pair increases in FDI integration are associated with more synchronized investment. However, this result is not robust to the inclusion of an aggregate time trend. In column (2), I include time fixed-effects to account for common global shocks, while column (3) reports results with both time fixed-effects and country-specific time trends. In both specifications, the coefficient on FDI integration remains

[14]Earlier work (e.g. Frankel and Rose (1998) or Kose and Yi (2006)) showed the importance of trade for aggregate business cycle co-movement. The positive point estimates suggest the existence of some complementarity between FDI and trade. Yet, the trade linkages are only moving slowly over time, so there might be too little within-country correlation to pick up significant effects.

Table 3: Bilateral FDI Linkages and GDP synchronization

Dependent Variable: GDP growth synchronization (annualized)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FDI/GDP	0.546*	0.104	0.312	0.314				
	(1.78)	(0.44)	(1.14)	(1.15)				
Trade/GDP				-0.0203				
				(-0.04)				
FDI/Total FDI					0.449	0.213	0.318	0.329
					(1.48)	(0.76)	(1.13)	(1.17)
Trade/Total Trade								-0.175
								(-0.37)
Country-pair fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Country trends	Yes	No	Yes	Yes	Yes	No	Yes	Yes
R-squared (within)	0.132	0.230	0.297	0.297	0.127	0.232	0.297	0.298
Observations	600	600	600	600	600	600	600	600

Notes: The table reports panel (country-pair) fixed-effect coefficients estimated over the period 1991 to 2006 for the 21 G7 country pairs. The dependent variable is minus one times the absolute value of the difference in quarterly growth rate of real GDP between country i and j in year t (the yearly estimate is obtained by averaging over the respective four quarterly estimates). In columns (1) - (4) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the previous year relative to the sum of the two countries' GDP in the previous year (denoted FDI/GDP). In columns (5) - (8) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the previous year relative to the sum of the two countries' total FDI Assets and FDI Liabilities in the entire world in the previous year (denoted FDI/Total FDI). All specifications also include the log of the two countries' per capita GDP, the log of the product of the two countries' population, and the log of the industrial specialization index as defined in the appendix; all controls are included with one period lag. The specification in (4) includes the log of the share of bilateral export and import flows between countries i and j in the previous year relative to the sum of the two countries' GDP in the previous year (Trade/GDP). The specification in (8) includes the log of the share of bilateral export and import flows between countries i and j in the previous year relative to the sum of the two countries' total exports and imports in the previous year (Trade/Total Trade). The specifications in columns (1) and (5) include country-specific linear time-trends. The specifications in columns (2) and (6) include time fixed-effects. The specifications in columns (3),(4),(7), and (8) include time fixed-effects and country-specific linear time-trends. Standard errors adjusted for panel (country-pair) specific auto-correlation and heteroskedasticity and corresponding t-statistics are reported below the point estimates. A † denotes significance at the 85% confidence level, * denotes significance at the 90% confidence level, ** denotes significance at the 95% confidence level, *** denotes significance at the 99% confidence level. For a detailed data description see appendix A.

positive but is statistically indistinguishable from zero. Specification (4) controls for bilateral trade linkages. The coefficient on goods trade is positive and bigger in size than the coefficient on FDI integration. Yet we cannot reject the Null of a zero coefficient.[15] From the table also emerges that controlling for goods trade does not affect the finding of a quantitative small and statistical insignificant link between FDI integration and GDP synchronization.

Columns (5) to (8) report the results using the alternative FDI integration index as defined in equation (5). The results are similar to the ones in columns (1) to (4), except that in specification (8) the coefficient on trade linkages becomes statistically significant at the 10 percent level. The results regarding FDI integration and GDP synchronization remain unchanged: there is no statistical significant link between FDI linkages and GDP synchronization.

3 A model of international business cycles with foreign direct investment

In this section, I develop a model of international business cycles where multinationals accumulate technology capital and engage in FDI. Technology capital is firm-specific and can be simultaneously used in multiple plants in locations at home and abroad.[16] The plants operatad by multinationals thus produce all with the same technology capital. There are two types of shocks causing economic fluctuations: a standard country-specific productivity shock and a shock that is multinational-specific, affecting the efficiency of the existing technology capital. This multinational-specific shock therefore affects both the returns on domestic and on foreign investment.

The model serves three purposes. The first is to precisely lay out a causal link between FDI openness and international investment synchronization. The empirical section documents a relationship between the two, but does not speak about the underlying mechanism and the direction of causation. I will use the model to derive quantitative results that show how the empirical findings are indeed consistent with the hypothesis that FDI openness has significant effects on investment synchronization. The second purpose of the model is to shed light on the weak link between FDI openness and GDP synchro-

[15] A reason for this finding could also be reverse causality: less correlated country pairs engage in more FDI. In this case, the presented coefficients presented here are lower bounds as this argument describes a downward bias for the un-instrumented estimates. For the theoretical argument, see (Heathcote and Perri, 2004).

[16] For the concept of locations in this context refer to McGrattan and Prescott (2009).

nization, as documented in the empirical section. For this purpose, I measure GDP in the model in the same way as in national accounts data where investments in intangible capital are expensed. With the quantitative results of the model, I show that FDI openness has indeed weak effects on business cycle synchronization when using measured GDP as a proxy for aggregate activity. Third, and relatedly, I use the model to conduct a counter-factual analysis to show that the relation between FDI openness and business cycle synchronization is significantly stronger when aggregate output is measured correctly.

The framework combines earlier work from Ramondo and Rappoport (2010) and McGrattan and Prescott (2009) to incorporate multinational production into an international business cycles set-up. The main innovation is that I consider both a stochastic environment and allow for an explicit role for FDI; as such, the set-up is well-suited to analyze the effects of cross-border FDI integration on investment synchronization. As will be shown below, a key ingredient of the model is the accumulation of technology capital.

3.1 The economy

I consider a two-countries, two-sectors, two-goods world. In each country (foreign variables are denoted by an asterisk), there are households of equal mass normalized to unity that consume a tradable final consumption good and supply labor to firms. Firms in the final good sector buy intermediate inputs from intermediate good firms, hire labor, accumulate physical capital and pay wages and dividends to domestic households. Physical capital and labor are not mobile across countries but across sectors. The intermediate good is not tradable across countries and producers in this sector buy differentiated goods from domestic and foreign firms, labelled multinationals. Multinationals can accumulate physical capital in both countries and set up production units both at home and abroad through which they serve the foreign intermediate goods market. Multinationals pay dividends to their owners, domestic multinationals are entirely owned by domestic households and foreign multinationals are entirely owned by foreign households.[17] In addition to physical capital, multinationals accumulate technology capital. Technology capital is firm-specific and can be used in multiple locations in both countries at the same time. For international financial markets, I consider two scenarios: one in which international financial markets are complete in the sense that households have access to a full set of state-contingent securities that can be traded internationally. The other scenario is one

[17] I exclude that firm shares are traded. Because financial markets are complete this is without loss of generality.

in which households cannot trade any international assets and just receive labor income and dividends from domestic firms and multinationals.

Time and uncertainty. Time is discrete and denoted by $t = 1, 2, \ldots$. In each period t the economy experiences one event $s_t \in S$ where S is a possibly infinite set. I denote by s^t the history of events up to and including date t. The probability at date 0 of any particular history s^t is given by $\pi(s^t)$. For the sake of readability (and with some abuse of notation), I will drop the explicit reference to histories and states most of the time when there is no room for confusion; I will use the subscript t instead to refer both to the time period and histories.

Households. Households supply labor and the total supply of time is normalized to $\bar{L}$; households derive utility from consumption of the perishable good C_t and from leisure $\bar{L} - L_t$. Households maximize the expected discounted sum of future period utilities given by

$$E \sum_{t=0}^{\infty} \beta^t U(C_t, \bar{L} - L_t)$$

where E represents expectations across all possible states of the world, C_t denotes consumption, L_t is labor effort, $0 < \beta < 1$ is the discount factor, and the period-by-period utility function is given by $U(C_t, \bar{L} - L_t) = \log(C_t) + \alpha \log(\bar{L} - L_t)$. Given aggregate wages w_t, households receive labor income $w_t L_t$ and dividend payments from domestic tradable good firms d_{Tt} and from multinationals d_{Mt}, respectively.

International financial markets. I consider two versions of the model, one with complete international financial markets and one with financial autarky, in the sense that households cannot trade any international assets.

1. In the **complete** financial markets scenario, households have available a complete set of Arrow securities. Let $B_t(s^t, s_{t+1})$ be the quantity of bonds purchased by the home households at time t after history s^t that pay one unit of the consumption good in $t+1$ if and only if the state of the world economy in $t+1$ is equal to s_{t+1}. Let $q_t(s^t, s_{t+1})$ be the price of such a bond. Under complete international financial markets, the budget constraint for the representative household in the home country is

$$C_t + \sum_{s_{t+1}} q_t(s^t, s_{t+1}) B_t(s^t, s_{t+1}) = w_t L_t + d_{Tt} + d_{Mt} + B(s^{t-1}, s_t) \quad (6)$$

and the budget constraint for foreign households is analogously defined.

2. Under **financial autarky**, households are not allowed to trade any financial asset across country borders. In this model version, the budget constraint for the representative household in the home country is

$$C_t = w_t L_t + d_{Tt} + d_{Mt}, \tag{7}$$

analogous for the foreign households.

Firms in the tradable goods sector. The tradable consumption good is produced under perfect competition with a constant returns to scale technology that combines labor (l_{Tt}), capital (k_{Tt}) and the composite intermediate good (X_t). Production in the this sector is subject to stochastic and country-specific productivity shocks a_t and a_t^*. Firms' production function is given by

$$Y_t = e^{a_t} \left(k_{Tt}^{\theta} l_{Tt}^{1-\theta} \right)^{\nu} X_t^{1-\nu}, \tag{8}$$

where $0 < \nu < 1$. Final good firms purchase X_t units of the intermediate good from competitive intermediate good producers at a unit price P_t, where I normalized the price of the tradable good to one. Firms' dividends are thus given by

$$d_{Tt} = e^{a_t} \left(k_{1t}^{\theta} l_{1t}^{1-\theta} \right)^{\nu} X_t^{1-\nu} - P_t X_t - w_t l_{Tt} - i_{Tt} \tag{9}$$

where i_{1t} represents investment in physical capital. The capital stock evolves according to

$$k_{Tt+1} = (1-\delta) k_{Tt} + \left[\frac{\chi_1 \left(\frac{i_{Tt}}{k_{Tt}} \right)^{1-\psi}}{1-\psi} + \chi_2 \right] k_{Tt} \tag{10}$$

where δ is the depreciation rate, ψ determines the sensitivity of the cost to investment, and the parameters χ_1 and χ_2 are set by imposing steady state targets.[18] I assume that the productivity shocks follow a bivariate auto-regressive process

$$\begin{bmatrix} a_t \\ a_t^* \end{bmatrix} = \Lambda_a \begin{bmatrix} a_{t-1} \\ a_{t-1}^* \end{bmatrix} + \begin{bmatrix} \varepsilon_t^a \\ \varepsilon_t^{a^*} \end{bmatrix} \tag{11}$$

[18]This functional form is widely used in the literature, see for example Quadrini and Jermann (2012). The parameters are chosen such that the depreciation rate is equal to δ and that the derivative of capital with respect to investment is equal to one.

where Λ_a is a 2×2 matrix and $[\varepsilon_t^a, \varepsilon_t^{a^*}]'$ is a vector of i.i.d. random variables with mean 0, standard deviation σ_a and correlation ρ_ε^a. The problem of domestic tradable goods firms is then

$$\max E \sum_t^\infty Q_t d_{Tt}$$

subject to (9), (10), k_{10} given, where $Q_t = \beta^t U_c(C_t, L_t)$ is the marginal utility of period t consumption of domestic consumers who are the owners of the firm. The problem of tradable good firms in the foreign country is analogous.

Intermediate good producers. Intermediate good producers buy non-tradables produced by multinationals and sell the bundled good Y_{It} at price P_t to final good producers. The index Y_{It} aggregates a continuum of intermediate goods with a constant elasticity of substitution $\frac{1}{1-\eta}$. As discussed in more detail below, I assume that there are only two types of firms in each country: (i) domestic multinationals and (ii) foreign multinationals. Given this assumption, intermediate good producers' output reads as

$$Y_{It} = \left[\int x_t(i)^\eta \right]^{\frac{1}{\eta}} \tag{12}$$

where $x_t(i)$ denote the intermediate good producers' demand for goods produced by domestic and foreign multinationals, respectively. The implied demand functions are given by

$$x_t(i) = (P_t / p_t(i))^{\frac{1}{1-\eta}}. \tag{13}$$

The main effect of adding imperfect competition to the model is that it scales up the amount of variable profits in the economy; hence, it scales up the size of the payments owners receive from technology capital, something that does not affect the qualitative implications of the model but is necessary to obtain realistic amounts of FDI when undertaking the quantitative analysis below.

Multinationals. In both countries, there is a large number of firms, labelled multinationals because of their ability to potentially produce both at home and abroad. The mass of firms is constant and normalized to one.[19] In each country, there is a large

[19] We do abstract from entry and exit considerations. One should think of it in the following way. If a domestic multinational wants to enter the domestic market, it has to buy the product or market by an existing multinational that has to exit. In that way, the mass of firms active stays constant. Please also note that we do not allow domestic firms to buy other firms' assets or product lines. This is an interesting future line of research.

number of locations where production can take place.[20] The measure of locations is, without loss of generality, normalized to one. In each location, both domestic and foreign multinationals can set up a plant and operate. The production of a plant owned by a domestic multinational in a given location i depends on firm specific productivity z_t, labor services $l_t(i)$ and physical capital $k_t(i)$ and is given by a decreasing returns to scale technology $y_t(i) = e^{z_t}(k_t(i)^\theta l_t(i)^{1-\theta})^{1-\phi}$ with $0 < \phi < 1$. While physical capital and labor are both specific to each multinational and plant, technology capital M_t and productivity z_t is specific to each multinational only. The productivity of the foreign multinational is denoted by z_t^*. Technology capital and productivity therefore affect production in all locations, both domestic and foreign, in which the firm operates. A home multinational with M_t units of technology capital, k_{dt} units of domestic physical capital, and l_{dt} units of domestic labor services efficiently allocates physical capital and labor across all M_t domestic plants. Therefore, its total production in the home country is given by

$$y_{dt} = e^{z_t} M_t^\phi \left(k_{dt}^\theta l_{dt}^{1-\theta}\right)^{1-\phi}. \tag{14}$$

Technology capital can also be used to set up operations in a foreign location. Foreign owned multinationals accumulate domestic physical capital and hire domestic labor services and use their own technology capital. In contrast to domestic firms, the production of a foreign multinational depends on the countries' FDI openness. The degree of openness to FDI for both countries is given by a parameter τ that determines the total average factor productivity of a foreign multinational relative to a domestic multinational.[21] To illustrate this point, consider a multinational owned by the domestic consumer with given technology capital M_t and productivity z_t. It allocates efficiently its foreign physical capital k_{ft} and foreign labor services l_{ft} to generate total output abroad given by

$$y_{ft} = \tau e^{z_t} M_t^\phi \left(k_{ft}^\theta l_{ft}^{1-\theta}\right)^{1-\phi}. \tag{15}$$

Analogously, a foreign owned multinational with M_t^* units of technology capital and productivity z_t^*, k_{ft}^* units of home country's physical capital, and l_{ft}^* units of home country's labor services produces total output in the home country according to

$$y_{ft}^* = \tau e^{z_t^*} (M_t^*)^\phi \left((k_{ft}^*)^\theta (l_{ft}^*)^{1-\theta}\right)^{1-\phi}. \tag{16}$$

[20]The derivation of the multinationals' production technology follows closely McGrattan and Prescott (2009); see also Kapicka (2012).

[21]Here, we impose symmetry across countries and assume that both countries have the same degree of openness.

The domestic multinationals' total dividends are then given by the proceeds from their domestic and foreign operations, respectively, or

$$d_{Mt} = (p_{dt}y_{dt} - w_t l_{dt} - i_{dt}) + (p^*_{ft}y_{ft} - w^*_t l_{ft} - i_{ft}) - i_{Mt} \tag{17}$$

where the inverse demand functions p_{dt}, p^*_{ft} of domestic and foreign intermediate good producers defined in (13) are taken as given; i_{dt} and i_{ft} represent investment in domestic and foreign physical capital, respectively, and i_{Mt} represents the multinationals' investment in technology capital. The respective capital stocks evolve according to

$$k_{jt+1} = (1-\delta)k_{jt} + \left[\frac{\chi_1\left(\frac{i_{jt}}{k_{jt}}\right)^{1-\psi}}{1-\psi} + \chi_2\right]k_{jt} \qquad j = d, f \tag{18}$$

$$M_{t+1} = (1-\delta_m)M_t + \left[\frac{\chi_1^m\left(\frac{i_{Mt}}{M_t}\right)^{1-\psi_m}}{1-\psi_m} + \chi_2^m\right]M_t \tag{19}$$

where δ_m is the depreciation rate of technology capital, ψ_m determines the sensitivity of the cost to investment in technology capital, and the parameters χ_1^m and χ_2^m are set by imposing steady state targets.[22] Note that the parameters for the adjustment costs in physical capital are identical across sectors. To complete the description of the multinationals problem, I assume that the log of domestic and foreign multinationals' productivity evolves according to a bivariate auto-regressive process

$$\begin{bmatrix} z_t \\ z^*_t \end{bmatrix} = \Lambda_z \begin{bmatrix} z_{t-1} \\ z^*_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon^z_t \\ \varepsilon^{z^*}_t \end{bmatrix} \tag{20}$$

where Λ_z is a 2×2 matrix and $[\varepsilon^z_t, \varepsilon^{z^*}_t]'$ is a vector of i.i.d. random variables with mean 0, standard deviation σ_z and correlation ρ_z. Multinationals resident in the home country solve

$$\max E \sum_t^{\infty} Q_t d_{Mt}$$

subject to (13),(17), (18), (19), M_0, k_{d0}, k_{f0} given, where Q_t again is the marginal utility of consumption of the domestic consumers (who are the owners). The problem of foreign owned multinationals is analogous.

[22] I set the parameters such that the depreciation rate in steady state is equal to δ_m and the derivative of technology capital with respect to investment is equal to one.

3.2 Equilibrium

An equilibrium, for an exogenously given level of FDI openess τ, is a collection of price sequences p_{dt}, p^*_{dt}, p_{ft}, p^*_{ft}, P_t, P^*_t, Q_t, Q^*_t , $q(s^t, s_{t+1})\ \forall s_{t+1} \in S$, exogenous shock processes z_t, z^*_t, a_t, a^*_t and quantities C_t, L_t, i_{Tt}, i_{dt}, i_{ft}, i_{Mt}, l_{Tt}, l_{dt}, l_{ft}, d_t, x_{dt}, x_{ft}, y_{dt}, y_{ft}, X_t, Y_{It}, Y_t, $B(s^t, s_{t+1})$, C^*_t, L^*_t, i^*_{Tt}, i^*_{dt}, i^*_{ft}, i^*_{Mt}, l^*_{Tt}, l^*_{dt}, l^*_{ft}, d^*_t, x^*_{dt}, x^*_{ft}, y^*_{dt}, y^*_{ft}, X^*_t, Y^*_{It}, Y^*_t, $B^*(s^t, s_{t+1})\ \forall s_{t+1} \in S$ such that:

1. Given prices and shocks, consumers and firms solve their respective problems.
2. Labor markets clear, i.e.

$$L_t = l_{dt} + l^*_{ft} + l_{Tt} \qquad \text{for all } t.$$
$$L^*_t = l^*_{dt} + l_{ft} + l^*_{Tt} \qquad \text{for all } t.$$

3. Intermediate goods markets clear, i.e.

$$X_t = Y_{It} \qquad X^*_t = Y^*_{It} \qquad \text{for all } t.$$
$$x_{dt} = y_{dt} \qquad x_{ft} = y^*_{ft} \qquad x^*_{dt} = y^*_{dt} \qquad x^*_{ft} = y_{ft} \qquad \text{for all } t.$$

4. Under complete financial markets bond markets clear, i.e.

$$B(s^t, s_{t+1}) + B^*(s^t, s_{t+1}) = 0 \qquad \text{for all } t, s_{t+1} \in S.$$

5. The tradable goods market clears, i.e.

$$C_t + C^*_t + i_{Tt} + i^*_{Tt} + i_{dt} + i_{ft} + i^*_{dt} + i^*_{ft} + i_{Mt} + i^*_{Mt} = Y_t + Y^*_t \qquad \text{for all } t.$$

3.3 National accounts and measured returns

Because in national accounts investment in technology capital is expensed,measured gross domestic product in the home country is given by[23]

$$GDP_t = Y_t - i_{Mt}. \tag{21}$$

[23]The equation follows by adding up aggregate labor income $w_t L_t$, firms' dividends and depreciation of physical (or tangible) capital. The crucial assumption is that technology capital is intangible and therefore not taking into account when computing aggregate income. See also McGrattan and Prescott (2010).

This means that GDP differs from actual value added Y_t whenever investment in technology capital is different from zero. This also implies that the dynamic properties of GDP - in particular cross country correlations - depend both on output and investment in technology capital.

Gross FDI positions are given by

$$FDIA_t = k_{ft} \qquad FDIL_t = k^*_{ft}$$

and total bilateral FDI linkages are computed in line with the empirical estimates[24]

$$FDI/GDP = \frac{2(FDIA_t + FDIL_t)}{4(GDP_t + GDP^*_t)}.$$

In terms of measurement, other key variables are the returns on FDI. Returns reported in balance of payment statistics e.g. by the BEA do not coincide with the *actual* returns multinationals receive from foreign direct investment.[25] To see this in the present setup, consider the actual return domestic multinationals receive from their subsidiaries abroad

$$r_{ft} = \theta\eta(1-\phi)\frac{p^*_{ft}y_{ft}}{k_{ft}} - \delta.$$

In the data, measured returns of foreign subsidiaries from the abroad are computed as FDI income (dividends plus reinvested earnings) divided by the tangible capital stock owned by the multinationals. In the notation of my model, measured returns for the domestic multinational from its subsidiaries abroad are given by

$$r_{FDI,t} = \frac{p^*_{ft}y_{ft} - w^*_t l_{ft} - \delta k_{ft}}{k_{ft}} = r_{ft} + (1-(1-\phi)\eta)\frac{p^*_{ft}y_{ft}}{k_{ft}}. \qquad (22)$$

As the returns on technology capital are not taken into account, measured returns differ from the actual returns by the second term in the above expression. In order to calibrate of the multinational-specific shock, I will match the volatility of measured returns pubilshed by the BEA, as outlined in more detail in the next sub-section.

Table 4: Parameter values

Description	Symbol	Model		
		Complete Markets	Complete markets, both shocks	Financial autarky, both shocks
Preferences				
Discount factor	β	0.99		
Total time endowment	$\bar{L}$	3		
Weight of leisure	α	1.604	1.609	0.956
Technology				
Income share of labor in production	θ	0.31		
Share of intermediate goods in tradables	ν	0.50		
Income share of technology capital	ϕ	0.21		
Elasticity of demand interm. good sector	$\frac{1}{1-\eta}$	10		
Degree of FDI openness	τ	0.22	0.22	0.22
Depreciation and adjustment costs				
Depreciation physical capital	δ	0.025		
Depreciation technology capital	δ_m	0.0375		
Adjustment cost physical capital	ψ	0.112	0.112	0.135
Adjustment cost technology capital	ψ_m	0.105	0.110	0.150
Std. dev. prod. shock	σ_a	0.007	0.006	0.008
Std. dev. techn. capital efficiency shock	σ_z	0.000	0.009	0.008
Cross-country correlation prod. shock	$\rho_a = \rho_z$	0.000	0.000	0.000
Autoregessive coefficients	$\Lambda_a = \Lambda_z$	$\begin{bmatrix} 0.95 & 0 \\ 0 & 0.95 \end{bmatrix}$		

3.4 Calibration

The equilibrium described above does not admit an analytical solution. I therefore derive a numerical solution using standard linearization techniques. For this purpose, I need to assign numerical values to the various parameters. Table 4 shows the parameters used in the calibration for the three model specifications considered: (1) the model with complete financial markets and country-specific productivity shocks only, (2) the model with complete financial markets with both country-specific productivity shocks and mutlinational-specific shocks to the efficiency of technology capital, and (3) financial autarky with both shocks.

The discount factor is set to $\beta = 0.99$ implying an average interest rate of 4 percent. The

[24]Note that quarterly GDP in the model is annualized because also in national accounts, quarterly gross domestic product is reported at annualized levels.

[25]This was first pointed out by McGrattan and Prescott (2010).

share of intermediate inputs in final tradable production ν is set to 0.5, following Alvarez and Lucas (2007).[26] For the demand elasticity of substitution in the intermediate sector I follow Atkeson and Kehoe (2005) and set η to 0.9, implying mark-up of 11 percent and an elasticity of substitution of 10. For the depreciation of physical capital, I choose a standard value and set δ equal to 0.025. Regarding the depreciation of technology capital, I use $\delta_m = 0.0375$, implying an annual depreciation rate of 15 percent, that is, the BEA estimate for depreciation of R&D capital.[27]

As outlined in the following paragraphs, the remaining parameters are chosen in order to match key moments of the data. This includes also the parameters for the stochastic processes because - even in the model with country-specific productivity shocks only (a_t, a_t^*) - there is not a one-to-one mapping between the stochastic processes and the Solow residual obtained from the data because GDP is mismeasured. Table 5 reports the data targets and the model fit.

Utility and production. The weight on leisure in the utility function α is set so that households, on average, work one third of the available time. By normalizing the total time endowment to $\bar{L} = 3$, this implies a long-run target for employment equal to one. For the share of technology capital in multinationals' production (ϕ), I follow McGrattan and Prescott (2009) and match average investment in technology capital over GDP equal to eight percent. The share of capital in production (θ) is then set so that in steady state the labor share is 64 percent. The degree of FDI openness (τ) is set so that the bilateral FDI position in the model - measured as in the data according to equation (4) - is equal to 1.7 percent, that is, the median value of bilateral FDI linkages in the data, shown in table 1 row five, column seven.

Adjustment costs. Adjustment costs for both physical capital (ψ) and technology capital (ψ_m), respectively, are set so that the hp-filtered investment series of both types of capital are three times as volatile as hp-filtered GDP. For physical capital, this is a standard value and consistent with OECD data. For technology capital, the number requires some discussion. Ouyang (2011) reports that the growth rate of R&D expenditures are 1.6 times as volatile as GDP growth rates; on the other hand, Eisfeldt and Papaniko-

[26] Even though in their model the only input in production is labor, the model is calibrated in a way that is perfectly consistent to my setup, as they compute the share of effective labor which includes capital.

[27] See Eisfeldt and Papanikolaou (2013). Also McGrattan and Prescott (2010) or Kapicka (2012) assume that technology capital depreciates faster than physical capital. For the main results of this paper, this assumption is not crucial. The quantitative implications are affected but not sensitive for reasonable perturbations of this parameter (between 0.01 and 0.15).

Table 5: Targeted data moments and model fit

	Data	Model		
		Complete Markets	Complete markets, both shocks	Financial autarky, both shocks
Long-run averages				
Labor income share	64	64	64	64
Investment in technology capital over GDP	8	8.0	8.0	8.0
FDI/GDP	1.5	1.5	1.5	1.5
Second moments				
Std. dev. of GDP	1.3	1.3	1.3	1.2
Std. dev. of investment in physical capital relative to GDP	3	3.0	3.0	3.0
Std. dev. of investment in technology capital relative to GDP	3	3.0	3.0	2.7
Std. dev. FDI returns	1.6	0.8	1.6	1.6

Notes: This table presents the target moments used for the calibration. I compare the moments in the data to the averages of the models' stationary distributions obtained by simulating 150000 time periods and dropping the first 50000. The labor income share and returns on FDI are computed from US data, published by the BEA. The remaining data moments are the median values across time and countries for the OECD sample, see table 1. For a detailed description of the data see appendix A. Column two shows the data moments. Column three refers to the model with complete financial markets and country-specific productivity shocks in the tradable sector only. Column four shows the implied moments from the model with complete financial markets and both country-specific productivity shocks in the tradable sector and multinational specific shocks to the efficiency of technology capital. Column five shows the moments for the model under financial autarky and both shocks.

laou (2013) find that the volatility of the investment rate in organizational capital is 1.5 percent (annual).[28] Targeting the latter value would imply in this model that investment in technolgy capital was six times as volatile as GDP. Because I adopt the broader definition of technology capital (marketing expenditures plus organizational capital plus R&D) and R&D is the largest part in technology capital,[29] I choose a value in between and assume that investment in technology capital behaves similar to investment in physical capital in terms of volatility, in line with the findings in Wälde and Woitek (2004) for R&D investment and G7 data. It is worth noticing that the selected adjustment costs on investment in physical capital are quiet low compared to standard business cycle models; the presence of technology capital makes investment in physical capital less volatile.

[28]They define the investment rate as aggregate investment divided by the existing capital stock, see Eisfeldt and Papanikolaou (2013) table II.

[29]See McGrattan and Prescott (2010).

Exogenous shocks. For the stochastic processes I assume that the transition matrices are the same $\Lambda_a = \Lambda_z$, with a value of 0.95 on the diagonals and zero on the off-diagonals. Multinational-specific productivity shocks are perfectly correlated within countries (all domestic multinationals have the same productivity) and not correlated across countries (foreign multinationals' productivity follows a statistically independent stochastic process). The volatility of productivity in the tradable sectore (σ_a) and its cross-country correlation (ρ_a) are set so that measured GDP in the model matches the standard deviation of GDP in the data (1.3 percent) and the median value of the hp-filtered cross-country GDP correlation in the data (0.5, see table 1), respectively. For the model specifications with multinational-specific shocks (z_t, z_t^*), I choose the volatility σ_z such that the volatility of measured FDI returns as defined in equation (22) matches the reported volatility in the data, equal to 1.6 percent annualized.[30]

3.5 Impulse responses

This subsection presents the dynamic responses to the two types of shocks in separation. This serves two purposes. First, I show in what respects multinational-specific shocks differ from country-specific productivity shocks, in terms of model dynamics. Second, this allows me to illustrate how the transmission of these two shocks changes as countries open up to FDI. I therefore present both the impulse responses for country pairs with relatively little FDI linkages (i.e. a low τ) and countries with large FDI linkages (i.e. high τ).

3.5.1 Productivity shocks

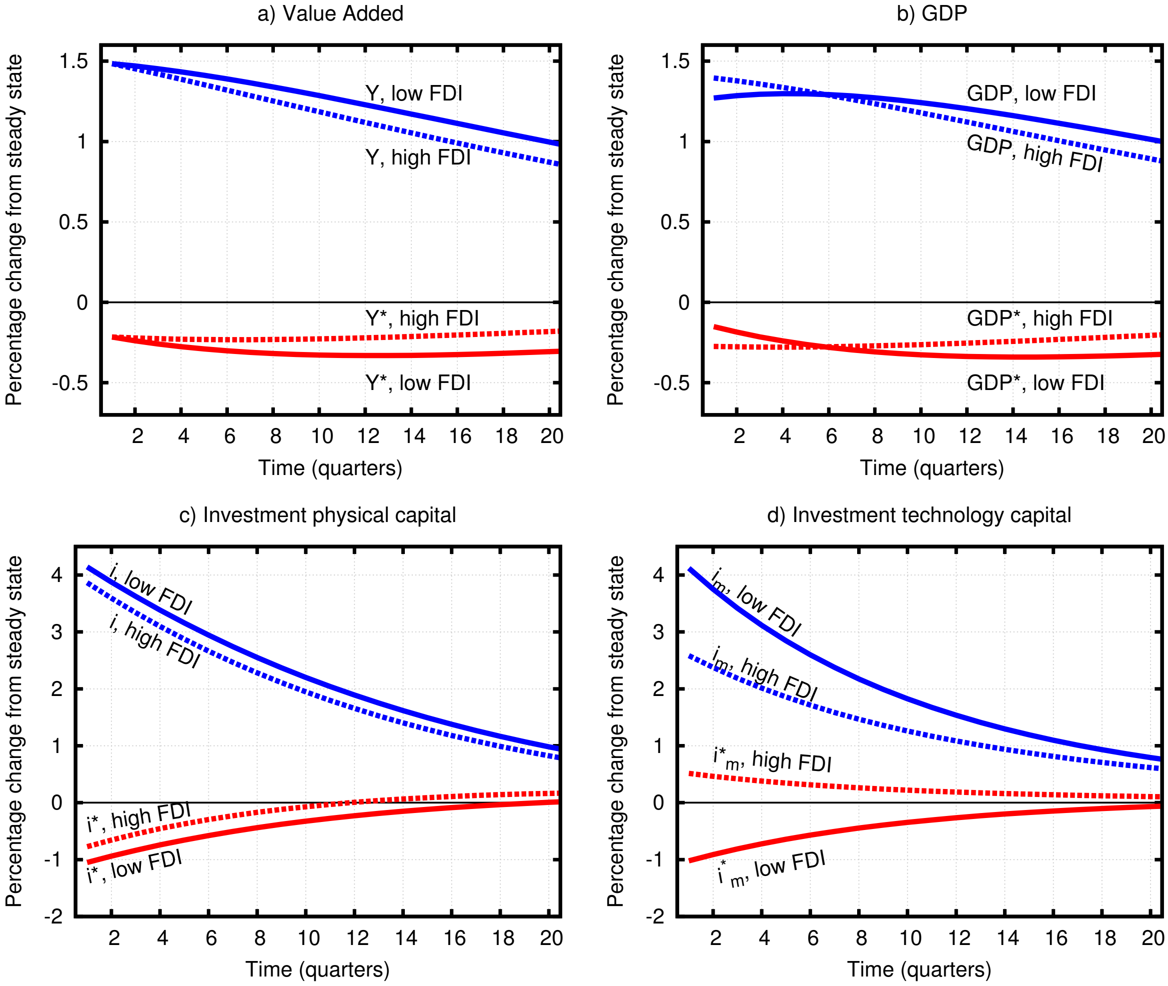
Figure 1 shows the impulse responses to a positive productivity shock in the home country's tradable sector for value added, measured GDP, and investments in physical and technology capital. Blue lines refer to the domestic country, the red lines to the foreign country. Solid lines refer to a country pair that is relatively closed to FDI, dashed lines refer to a relatively open country pair in terms of FDI.[31] Three observations emerge.

First, both actual value added (panel a) and GDP (panel b) increase in the home country while both show relatively little response in the foreign country. At the same time, investment in physical capital (panel c) and investment in technology capital (panel d)

[30]Note that the estimate in the data comes from the BEA and is the average over US inward and outward FDI income (see data appendix for a description of the data).

[31]For space considerations, the shock process itself is not shown. I consider a one-standard deviation shock in period 1; all plotted responses are normalized by the standard deviation of the shock.

Figure 1: Impulse responses to a productivity shock: low versus high bilateral FDI linkages



Notes: The figure shows impulse responses to a one-standard deviation positive productivity shock of one standard deviation in the home country (ε_t^a). All responses are in percentage deviations from the steady state, normalized by the standard deviation of the shock. Solid lines refer to the relatively closed country pair (low τ), dashed lines refer to the relatively open country pair (high τ). Blue lines refer to the home country, red lines to the foreign country. Panel a) plots the impulse responses for value added (Y_t and Y_t^*) as defined in equation (8), panel b) for measured GDP (defined as $Y_t - i_{mt}$), panel c) for investment in physical capital ($i_t = i_{Tt} + i_{dt} + i_{ft}^*$ and $i_t^* = i_{Tt}^* + i_{dt}^* + i_{ft}$), and panel d) for investment in technology capital (i_{Mt} and i_{Mt}^*).

increase in the home country and fall in the foreign country; notably, the on-impact increase of investments in the home country exceeds the fall in the foreign country by a factor four.

Second, technology capital behaves differently to a domestic productivity shock when countries are relatively more open to FDI (dashed lines); while the on-impact increase in technology capital investment in the home country decreases from four to two and a half percent, the response of foreign investment in technology capital switches sign and actually turns positive. Hence, when countries are relatively more open to FDI, a positive productivity shock in the home country benefits both domestic and foreign multinationals, whose dividends increase. Because the shocks are persistent, the expected returns on technology capital increase. Within a firm, in turn, all returns are equalized, therefore the returns both on foreign and domestic investment (from the firms' perspective) increase. As a consequence, foreign multinationals invest not only more in technology capital, but also more in physical capital both at home and abroad. On the other hand, because part of the additional returns of the increased domestic productivity benefits foreign firms, domestic firms increase their investments by a smaller amount than it would be the case when countries are relatively closed to FDI. The previous discussion is reflected by the responses of countries' aggregate investment in physical capital shown by the dashed lines in panel c). The responses shift move closer together, meaning that domestic and foreign investment become less negatively correlated.

Third, actual value added and measured GDP - shown in panels a) and b) - do qualitatively not respond differently when varying the countries' openness to FDI (compare the solid versus dashed lines). The only notable difference is the on-impact response in measured GDP: because investment in technology capital responds less positive in the home country compared to the closed case, GDP increases by more on impact (and the reverse for the foreign country). The transition dynamics however are largely unaffected, suggesting that GDP correlations become somewhat more negative with increasing FDI integration.

3.5.2 Shocks to multinational activity

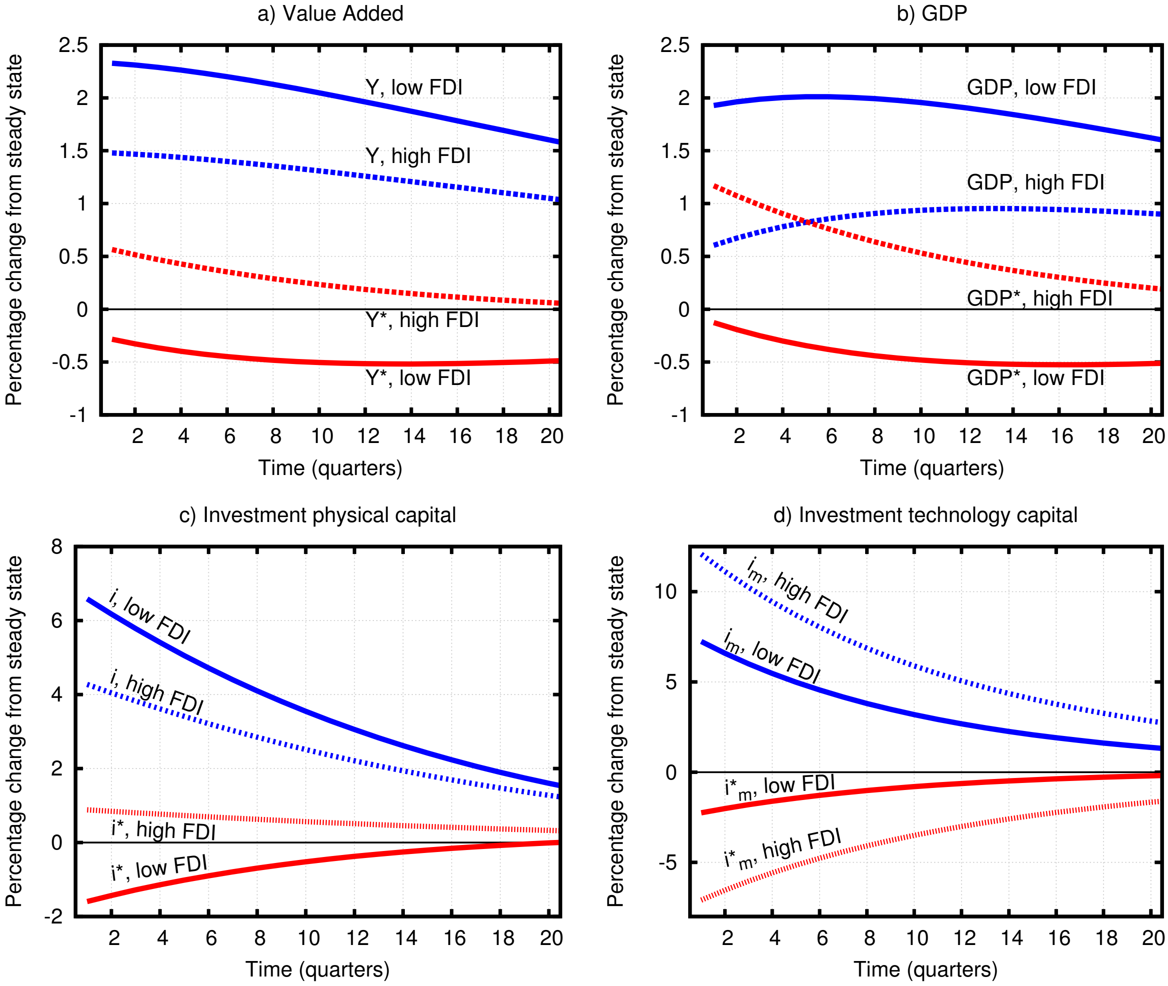
Figure 2 shows the impulse responses to a positive shock to domestically owned multinationals' productivity (ε_t^z) for value added, measured GDP, and investments in physical and technology capital, respectively. Blue lines refer to the domestic country, red lines to the foreign country. The solid lines refer to a country pair that is relatively closed to FDI, dashed lines refer to a relatively open country pair in terms of FDI.[32]

For relatively closed countries (solid lines) multinational-specific shocks work very much like standard productivity shocks, moving all quantities in a similar fashion as described in the previous sub-section. The reason is that in this case the share of foreign firms is too small to affect aggregate quantities.

On the other hand, the picture changes when countries are relatively open to FDI (dashed lines). First, consider the responses of investment in technology capital shown in panel d).

[32] For space considerations, the shock process itself is not shown. I consider a one-standard deviation shock in period 1; all plotted responses are normalized by the standard deviation of the shock.

Figure 2: Impulse responses to a positive shock to multinational activity: low versus high bilateral FDI linkages



Notes: The figure shows impulse responses to a one-standard deviation positive shock to the efficiency of domestic multinationals (ε_t^z). All responses are in percentage deviations from the steady state and normalized by the standard deviation of the shock. Solid lines refer to the relatively closed country pair (low τ), the dashed lines refer to the relatively open country pair (high τ). Blue lines refer to the home country, red lines to the foreign country. Panel a) plots the impulse responses for value added (Y_t and Y_t^*) as defined in equation (8), panel b) for measured GDP (defined as $Y_t - i_{mt}$), panel c) for investment in physical capital ($i_t = i_{Tt} + i_{dt} + i^*_{ft}$ and $i^*_t = i^*_{Tt} + i^*_{dt} + i_{ft}$), and panel d) for investment in technology capital (i_{Mt} and i^*_{Mt}).

The dashed blue lines lies above the solid blue line, meaning that domestic multinationals increase their investment in technology capital by more than in the closed economy case. The reason is that domestic multinationals gain from investments in technology capital because of the relatively higher returns from abroad. Similarly, the red dashed line lies below the red solid line meaning that foreign multinationals investments in technology capital decrease by more than compared to the case with low FDI linkages.

This, in turn, affects the profitability of investment in physical capital, so it is rational for the multinationals to invest more at home and abroad. This is reflected by the increase in aggregate investment both at home and abroad, as shown by the dashed lines in panel c). Note that this also implies that the increase in investment in physical capital in the home country is below the solid blue line in panel c) because part of the resources get redirected to the foreign country. As a consequence, international investment becomes more synchronized when countries are relatively open to FDI. Hence, multinational-specific shocks exacerbate the effect of technology on the investment co-movement.

Finally, consider the responses of value added in panel a) and GDP in panel b) in the high FDI linkage scenario (dashed lines). The first notable observation is that value added in both countries increase in response to the shock. The reason is that part of the resources are shifted to the foreign country in form of additional investment of home owned multinationals leading to more output abroad. This is also reflected by the less positive response of value added in the home country (the dashed blue line lies below the solid blue line). Measured GDP - as shown by the dashed lines in panel b) - reflects not only the movements of value added but also the responses in investment in technology capital. Because domestic investment in technology capital responds relatively more when FDI linkages are high, the impulse response of domestic GDP shifts towards South-East such that it even crosses the response of foreign GDP. That means that - on impact - measured GDP abroad increases by more than domestic GDP. In the subsequent transition then, domestic GDP rises, while foreign GDP falls. This suggests that measured GDP might get even more negatively correlated when FDI openness increase.

4 Quantitative Results

4.1 Business cycle properties

In this section, I use the model to assess the business cycle implications of technology capital and shocks to multinational activity. For this purpose, I compare the long-run business cycle statistics for the three model specifications. Table 6 reports the results of the quantitative exercise. The rows labelled "Complete Markets, prod. shock only" report business cycle statistics for the model with complete financial markets and productivity shocks only; the rows labelled "Complete markets, both shocks" refers to the model with complete markets and both productivity shocks and shocks to the efficiency of technology capital; the rows labelled "financial autarky, both shocks" refer to the financial autarky model with both shocks.

Table 6: Business cycle statistics

	GDP	Cons.	Inv.	Empl.	TFP	Net Exports
Volatilities		relative to GDP volatility				
Data	1.3	0.65	3.0	0.65	0.35	0.64
Complete markets, prod. shock only	1.3†	0.34	3.0†	0.65	0.60	0.46
Complete markets, both shocks	1.3†	0.35	3.0†	0.65	0.60	0.46
Financial autarky, both shocks	1.2†	0.75	3.0†	0.25	0.84	0.08
Correlation with GDP						
Data		0.69	0.83	0.66	0.87	-0.29
Complete markets, prod. shock only		0.59	0.96	0.95	0.97	0.71
Complete markets, both shocks		0.60	0.96	0.95	0.97	0.70
Financial autarky, both shocks		1.00	0.99	0.98	1.00	-0.90
International Correlation						
Data	0.37	0.19	0.26	0.16	0.19	
Complete markets, prod. shock only	-0.29	1.00	-0.43	-0.77	0.14	
Complete markets, both shocks	-0.28	1.00	-0.42	-0.77	0.16	
Financial autarky, both shocks	0.01	0.01	0.01	-0.00	0.01	

Notes: † denotes statistics matched in the calibration.

There are three notable results. First, all model versions generates business cycle statistics similar to those of standard international business cycle models which includes the well known short-comings. The complete market models imply perfect cross-country correlation of consumption, negative cross-country employment correlations, and pro-cyclical net exports. Interestingly, the complete market models generate volatilities of net exports in line with the data, while in the model with financial autarky volatility of net exports is too low compared to the data.

Second, and quiet interestingly, the cross-country correlation of consumption under financial autarky is equal to the correlation of GDP. This means the model can to some extend address the so called "quantity anomaly", that is, the fact that in the standard business cycle model consumption correlations are more positive than GDP correlations while in the data the opposite is true. One reason for this finding is the measurement issue for GDP. Recall that GDP is value added minus investment in technology capital. We will see below that when countries are relatively closed, measured GDP over-estimates the cross-country correlation of aggregate activity. This means that cross-country correlation of actual output is lower. In addition, when countries are relatively closed to FDI, cross-country correlations of consumption is closer to actual value added. The other reason is the presence of multinational-specific shocks that are uncorrelated across countries. Absent other international assets than FDI, households cannot insure this risk and consumption correlations are lower than without these shocks. I conjecture that for the same reasons the financial autarky model implies a cross-country correlation of employment in line with the data.

Third, the introduction of multinational-specific shocks leaves the business cycle moments mostly unaffected while it helps to match the volatility of measured returns. This confirms to some extent the validity of my calibration strategy where the volatility of the multinational-specific shocks was chosen in order to match the standard deviation of measured returns on FDI.

To summarize, the results in this section show that introducing technology capital and multinational-specific shocks into a standard international business cycle model generates plausible business cycle statistics, and helps to explain some features of the data the standard model has difficulties with.

4.2 FDI integration and business cycle synchronization

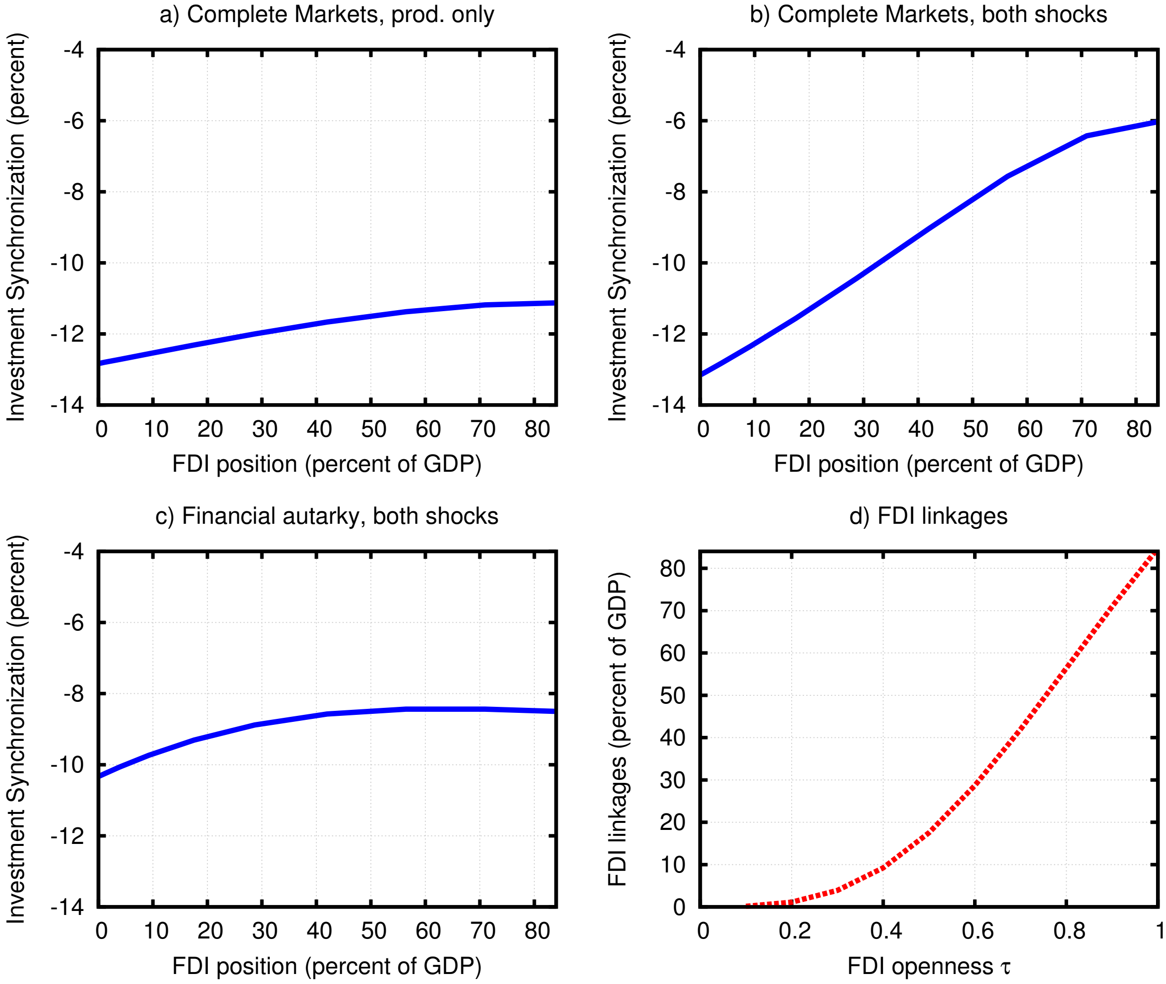
This sections connects the quantitative results of the model with the empirical results in the first part of the paper. I start by varying the FDI openness parameter τ and discuss how FDI openness affects co-movement of investment and GDP, respectively. Second, using artificial data generated by the model, I run the same regressions as in the data and compare the obtained regression coefficients. This is a simple test whether the causal relation in the model is consistent with the data. In addition, the model allows me to distinguish between measured GDP as reported in national accounts and actual value added and I will show how their co-movement patterns differ.

4.2.1 FDI openness and investment synchronization

For each model version as described above (complete markets with productivity shocks only, complete markets with both shocks, and financial autarky with both shocks), I vary the degree of FDI openness from very low integration ($\tau = 0.05$) to complete FDI openness ($\tau = 1$).[33] For each value of the financial integration parameter I report the average synchronization of investment as defined in equation (3). Figure 3 shows the results of this exercise. In all model versions, the slope of the line is always positive; a higher degree of FDI openness leads to more correlated investment cycles. This result is consistent with my regression estimates in table 2.

[33] I take a value for τ that is slightly bigger than zero for numerical reasons; a value of $\tau = 0.05$ implies a bilateral FDI to GDP ratio of 0.015 percent, i.e. the 2.5 percent quantile in the data.

Figure 3: FDI openness and investment synchronization

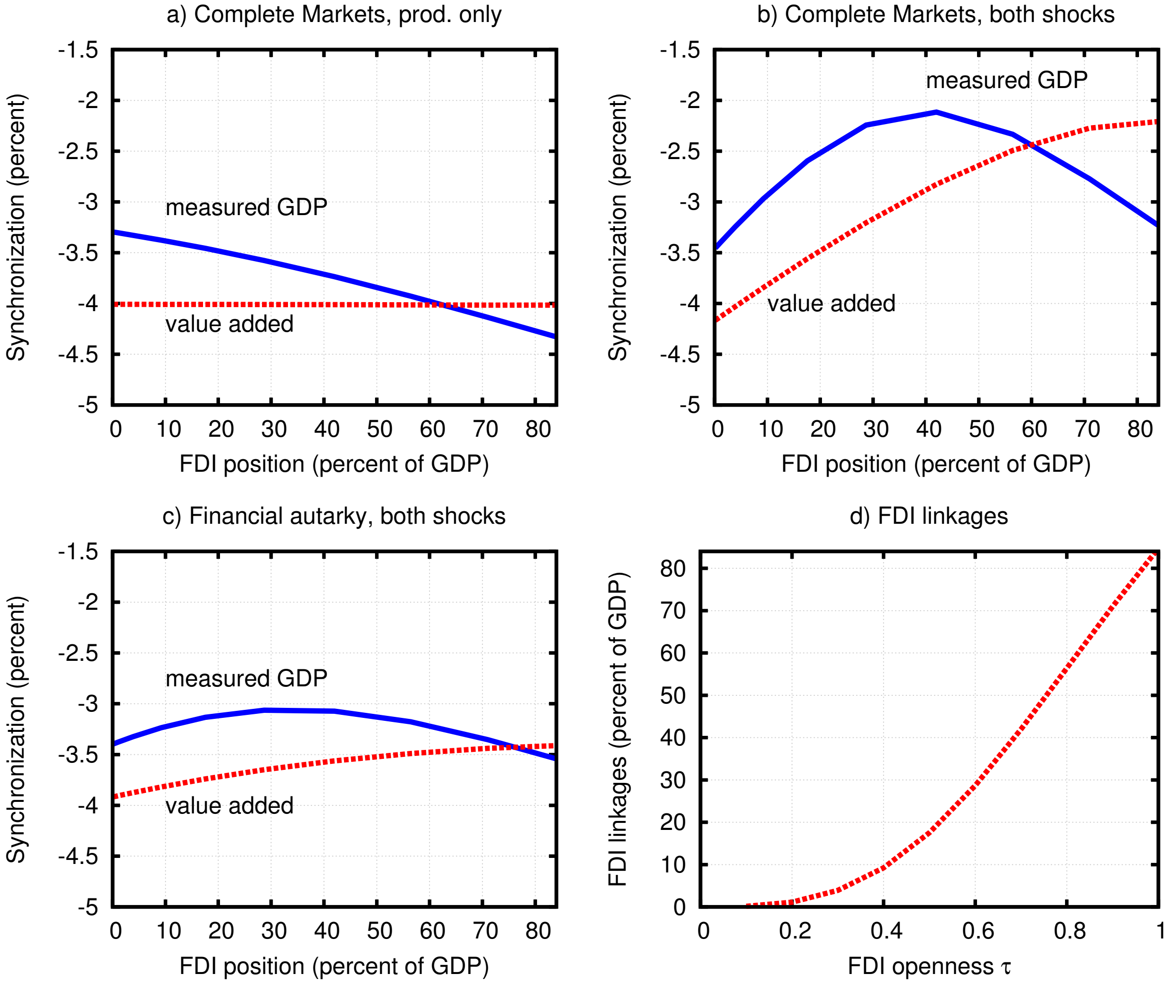


There are three main conclusions from the comparison of the three model versions. First, there is a clear ranking in terms of the slope of the increase in investment synchronization: the smallest in the model with complete markets and productivity shocks only (panel a)) and the strongest in complete markets and both productivity and technology capital shocks (panel b)). This suggest that both technology capital and multinational-specific shocks are quantitatively important for understanding investment co-movement.

Second, the slope of the increase in investment synchronization under financial autarky (panel c)) lies in between the two models with complete markets.[34] When households cannot trade any financial assets (recall that FDI is assumed to be the only asset and is undertaken by firms) and both shocks are active, there are two counter-acting forces: on the one hand, in response to country-specific productivity shocks, investment tends to

[34]When considering financial autarky with productivity shocks only, investment synchronization responds slighlty negative in response to variation in τ (not shown), see appendix.

Figure 4: FDI openness and GDP synchronization



flow to the more productive country and this weakens investment co-movement; on the other hand, when openness increases, firm-specific shocks to the efficiency of technology capital become more important and returns on investment within firm become more correlated. As described in section 3.5.2 this strengthens investment co-movement. As is evident in panel c), the latter force is dominating for most of the range of FDI openness τ.

Third, in all model versions, the increase in investment synchronization is fastest for middle ranges of FDI openness τ between 0.2 and 0.8; the reason behind this is the fact that, for these values of τ, the gains from FDI are biggest and FDI positions increase the fastest, as shown in panel d).

4.2.2 FDI openness and GDP synchronization

Let us now turn to the synchronization patterns of GDP as measured in national accounts (equation (21)) and actual value added (equation (8)). Again, for each model version (complete markets with productivity shocks only, complete markets with both shocks, and financial autarky with both shocks), I vary the degree of FDI openness from very low integration ($\tau = 0.05$) to complete FDI openness ($\tau = 1$).[35] For each value of the financial integration parameter I report the average synchronization of GDP and value added as defined in equation (2). The results are shown in figure 4.

In all model versions, synchronization patterns of measured GDP (blue solid lines) and value added (dashed red lines) behave quiet differently: while GDP shows a non-linear pattern in response to variations to FDI openness τ, synchronization of value added is constant (panel a)) or monotone increasing (panels b) and c)). This means that - due to the mismeasurement in GDP - actual cross country co-movement is overestimated for relatively closed country-pairs and underestimated when countries are relatively open to FDI.

We can gain some intuition by answering the following two questions. First, under complete markets with productivity shocks only (panel a)), why is GDP synchronization falling when FDI opennes increases? When FDI openness increases, a positive productivity shock in one country benefits multinationals from both countries due to their increased operations abroad. On impact, because expected returns increase, multinationals from both countries increase their investment in technology capital. The more the countries are open, the more similar in terms of size is this increase in investment in technology capital. Domestic investment in technology capital increases by relatively less and foreign investment in technology capital increases by relatively more when comparing a relatively open country pair to a relatively closed country pair. Everything else equal, by the definition of GDP (value added minus investment in technology capital), measured GDP at home is then relatively higher and GDP abroad is relatively lower; GDP is more negatively correlated.

Second, when looking at panels b) and c), why is GDP synchronization first increasing (for values of τ below 0.6) and then falling again (for values of τ above 0.6)? Consider first the complete market case as shown in panel b). In this model version, both country-specific and multinational-specific shocks are active. In the range of τ between 0.2 and 0.6 the returns of increasing FDI is biggest as discussed above and also shown in panel d). Therefore in this range, the country-specific and multinational-specific shock work in

[35]See footnote 33.

Table 7: Bilateral FDI linkages and synchronization: data vs. model

	Data	Model		
		Complete Markets	Complete markets, both shocks	Financial autarky, both shocks
Coefficient on investment synchronization	1.549 (0.629)	0.359	0.759	0.331
Coefficient on GDP synchronization	0.314 (0.027)	-0.145	0.093	0.019
Coefficient on synchron. of value added	n.a. n.a.	-0.000	0.196	0.052

Notes: The table reports the estimated coefficients in the three model versions. For convenience, column one reports the estimated coefficients obtained from the data, taken from column (3) in tables 2 and 3, respectively. For the empirical estimates, clustered standard errors (at the country-pair level) are reported in parenthesis below. The last three columns report the estimated coefficient of the three model versions. In the first row, the dependent variable is investment synchronization, in the second row GDP synchronization, and in the third row it is actual value added (Y). The right hand side variable in all regressions is log of the sum of bilateral FDI positions divided by the sum of the countries' GDP.

the same way and measured GDP resembles the synchronization pattern of value added (while the correlation of investment in technology capital is also increasing, see figure 1). Recall that following a positive shock to the domestic multinational, value added of both countries increases because the multinational invests in both countries more. At τ equal to approximately 0.6, however, there is a dipping point. Multinational-specific shocks dominate and investments in technology capital become negatively correlated, even exceeding the increase in correlation of value added. By the definition of GDP (value added minus investment in technology capital), GDP correlation therefore decreases.

Finally, under financial autarky, the pattern of GDP and value added synchronization resembles the pattern under complete markets. However, the lines in panel c are flatter than the ones in panel b). Incomplete markets dampen the amplitude of the synchronization of GDP and value added by the same amount. This is because under this secenario, the comparative static exercise is not really 'ceteris paribus'. Besides the effects of technology flows associated with more FDI as described under complete markets, varying the parameter τ picks up another force: the possibility of countries to shift resources across country borders, hence completing the markets in terms of risk sharing. In this sense for each value of τ the agents face a different international market structure and the effect of FDI on investment and output co-movement is downward biased.

4.2.3 Regression coefficients in the model and data

In this section, I run similar regressions on model data to the ones in the empirical part of the paper. In particular, I simulate the model for ten country pairs, varying the FDI openness parameter (τ) smoothly from zero to one. For each country pair I simulate the model for 48 quarters (12 years as in the data) and construct the same measure of Investment and GDP synchronization and for bilateral FDI linkages as used in the data analysis. I then convert the quarterly data to the yearly frequency by averaging across quarters. Finally, I regress the obtained synchronization measures on the log of bilateral FDI linkages. Table 7 reports the results for the three model versions considered. Note that, in the last row of the table, I report the synchronization measure for actual value added; in the model value added differs from measured GDP because investment in technology capital is expensed in national accounts. In the data, I do not have an equivalent measure available, for this reason I put "n.a." in the respective column. For comparison in table 7 I also report the coefficients on the same regression using actual data, repeating the estimates in column (3) in tables 2 and 3, respectively.

Three results emerge. First, I find that overall a higher degree of FDI integration leads to higher level of investment synchronization, as reflected in an integration coefficient between 0.186 and 0.831. Therefore the model explains up to 20 percent of the estimated coefficient in the data (4.106).

Second, the the sign of relation between FDI integration and GDP synchronization is ambiguous; the estimated coefficients in the model range from -0.092 to 0.159 where the latter value is very close to the coefficient obtained from actual data (0.129). This suggests that the relation between financial integration and output co-movement implied by our model is statistically close to the one we estimate in the data. In terms of magnitude, the estimated coefficients for GDP synchronization are significantly smaller than the coefficients obtained for investment synchronization, as observed in the data.

Third, as reported in the last row of table 7, actual co-movement of aggregate activity is larger than suggested by the estimates for GDP synchronization: the regression coefficients on actual value added range from -0.001 to 0.261, always lying above the estimates for GDP synchronization. This means that focussing on measured GDP as an indicator for co-movement underestimates the actual business cycle co-movement. To get a sense for the magnitudes, consider the estimated coefficients for the model version with complete markets and both shocks, reported in column two. The coefficient for GDP synchronization is 0.159 while the one for actual value added is 0.261. Hence, when focussing on GDP, a doubling of FDI linkages would lead to an increase in GDP synchronization of 0.159 percentage points. In contrast, for value added a doubling of FDI linkages leads to an increase in synchronization of 0.261 percentage points, a value that is 65 percent higher than the one for GDP synchronization. Therefore the model gives a theoretical rationale for a substantial bias due to measurement error that emerges because national accounts do not include intangible capital.

4.3 Robustness

TBC

5 Summary

In this paper, I document that FDI integration and investment synchronization are positively correlated and the relation between FDI linkages and GDP synchronization is - yet positive - quantitatively much smaller and indistinguishable from zero after controlling for common shocks. I then propose a tractable international business cycle model where multinational firms engage in FDI and multinational activity is subject to shocks. I show that the positive association between FDI openness and investment synchronization is consistent with the hypothesis that multinationals play an important role for the international transmission of shocks. The model also gives a rationale for the weak link between financial integration on GDP co-movement. Due to unmeasured intangible investments in GDP as constructed in national accounts, actual output co-movement is overestimated when countries are relatively closed and underestimated when countries are relatively open to FDI.

There are three main lessons from the theory. First, more FDI openness leads unambiguously to higher investment synchronization across country borders. This result holds in model specifications with complete and financial autarky, respectively.

Second, shocks to multinational activity are important to quantitatively account for the estimated link between FDI integration and investment synchronization. The regression coefficients estimated on artificial data from the model with multinational-specific shocks quantitatively explain 50 percent of the empirical regression coefficients, compared to 25 percent in the model version without multinational-specific shocks.

Third, because measured GDP is distorted, the effect of FDI linkages on actual output synchronization are higher than the the regression coefficients using GDP synchronization suggest.

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Appendix

A Data

Quarterly output and investment data are from OECD Quarterly National Accounts. The real series are annualized in constant US Dollars (OECD reference year), converted at fixed PPP exchange rates and seasonally adjusted (series VPVOBARSA). Correlations are the yearly average of 20 quarter rolling window estimates after HP-filtering data. The synchronization measures are calculated as explained in the main text. Yearly nominal GDP is from OECD National Accounts, annualized values in current US Dollars, converted at current PPP exchange rates, and seasonally adjusted (series CPCARSA). Bilateral outward and inward foreign direct investment data are from the OECD Foreign Direct Investment Database at a yearly frequency. Note that a general caveat of FDI data is that it is usually recorded at historical cost, so the FDI positions do not necessarily reflect actual market values. Total foreign direct investment data are from the OECD foreign direct investment data and from Lane and Milesi-Ferretti (2007). Bilateral exports and imports are from the OECD monthly trade statistics. Population data are from OECD labor market statistics. Industrial specialization in year t is calculated as in Imbs (2006); it is the absolute distance of the shares in value added of each sector in countries i and j, summing over all sectors. The data are from the OECD Statistics on Measuring Globalisation.

Table 8 summarizes the country pairs with all FDI data are available throughout the whole sample from 1990 to 2006 and 1995 to 2006, respectively. An exception is Japan, bilateral FDI data are available from 1985 to 1994 and 1996 to 2006 only, 1995 is not reported in the OECD database. For not deleting a G7 member from the analysis, I used linear interpolation to obtain the bilateral FDI positions for 1995.

Table 8: Country pairs used in empirical analysis

Balanced Sample, 1991 - 2006							
AUT,CAN	AUT,DEU	AUT,FRA	AUT,GBR	AUT,USA	CAN,DEU	CAN,FRA	CAN,GBR
CAN,ITA	CAN,JPN	CAN,NOR	CAN,USA	DEU,GBR	DEU,ITA	DEU,JPN	DEU,NLD
DEU,NOR	DEU,SWE	DEU,USA	FRA,DEU	FRA,GBR	FRA,ITA	FRA,JPN	FRA,NLD
FRA,NOR	FRA,SWE	FRA,USA	GBR,USA	ITA,GBR	ITA,JPN	ITA,NLD	ITA,USA
JPN,GBR	JPN,NLD	JPN,USA	NLD,GBR	NLD,USA	NOR,SWE	NOR,USA	SWE,USA

Notes: The table lists the country-pairs for which bilateral data were available in all years without gaps used in the respective samples. Essentially, it consists of the 21 G7 country pairs plus pairs involving Austria, Netherlands, Norway, and Sweden. Please read the note regarding the bilateral FDI positions reported by Japan in this appendix.

B Additional empirical results and robustness checks

This section presents several robustness checks for the empirical results in the main text. First, I include in the analysis only the 21 countries consisting of G7 countries between the years 1991 to 2006. Table 9 reports the results for investment synchronization. The main message remains, more bilateral FDI linkages are associated with more investment synchronization. The point estimates are of the same order of magnitude and do not differ between G7 country pairs and other country pairs. Note that the estimates significant different from zero for specifications in which interaction terms between FDI openness and industrial specialization and between trade openness and industrial specialization, respectively, are included. For that purpose I define a dummy variable that takes the value 0 if specialization is smaller or equal to the median specialization. For country-years in which specialization exceeds the median specialization, the dummy is equal to one.

Table 9: Bilateral FDI linkages and investment synchronization, G7 country pairs

Dependent Variable: Investment growth synchronization (annualized)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FDI/GDP	1.538*	0.537	1.752**	1.716**				
	(1.85)	(1.24)	(2.62)	(2.78)				
Trade/GDP				0.525				
				(0.25)				
FDI/Total FDI					0.492	0.635	1.430**	1.544***
					(0.59)	(1.33)	(2.42)	(2.90)
Trade/Total Trade								-1.315
								(-0.61)
Country-pair fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Country trends	Yes	No	Yes	Yes	Yes	No	Yes	Yes
R-squared (within)	0.160	0.357	0.387	0.387	0.154	0.358	0.385	0.385
Observations	315	315	315	315	315	315	315	315

Notes: The table reports panel (country-pair) fixed-effect coefficients estimated over the period 1991 to 2006 of the G7 countries plus country pairs involving Austria, Netherlands, Norway, and Sweden (in total, 40 country pairs). These are all countries for which bilateral FDI positions are available for all years. The dependent variable is minus one times the absolute value of the difference in quarterly growth rate of aggregate investment between country i and j in year t (the yearly estimate is obtained by averaging over the respective four quarterly estimates). In columns (1) - (4) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the previous year relative to the sum of the two countries' GDP in the previous year (denoted FDI/GDP). In columns (5) - (8) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the previous year relative to the sum of the two countries' total FDI Assets and FDI Liabilities in the entire world in the previous year (denoted FDI/Total FDI). All specifications also include the log of the two countries' GDP per capita, the log of the product of both countries' populations in the previous year, trade openness measured by Trade/GDP (in spec. (1) to (4)) or Trade/Total Trade (in spec. (5) to (8)), and the log of an index measuring industrial specialization, all lagged by one period (year). The specification in (4) includes an interaction term between FDI/GDP and a dummy variable (Dspec) that takes on the value one if the specialization index of a country pair is bigger than the median specialization of the sample and zero otherwise. Analogously it includes the same interaction term for Trade/GDP (not reported). Specification (8) includes an interaction term between FDI/Total FDI and a dummy variable (Dspec) that takes on the value one if the specialization index of a country pair is bigger than the median specialization of the sample and zero otherwise. The specifications in columns (1) and (5) include country-specific linear time-trends. The specifications in columns (2) and (6) include time fixed-effects. The specifications in columns (3), (4), (7), and (8) include time fixed-effects and country-specific linear time-trends. Standard errors adjusted for panel (country-pair) specific auto-correlation and heteroskedasticity and corresponding t-statistics are reported below the estimated coefficients. † denotes significance at the 85% confidence level, * denotes significance at the 90% confidence level, ** denotes significance at the 95% confidence level, *** denotes significance at the 99% confidence level. For a detailed data description see appendix A.

The results for GDP synchronization are as for G7 countries only. The point estimates are positive but not statistically different from zero, even when including interaction terms between FDI openness and specialization and trade openness and specialization.

Second, in table 11 and 12, I report regressions for HP-filtered data. For this purpose, I regress the 20 quarter cross-correlation of HP-filtered data in period t on FDI and trade openness in year $t-5$, that is, the initial value of the 20-quarter window. All other controls (log of product of GDP per capita, log of product of population, log of industrial specialization index) are also lagged by 5 years. Note that qualitatively the results remain the same when regressing the correlations on the 5 year averages of the time windows (not reported, available upon request). I prefer the former specification because there is more likelihood that exogeneity of the regressors and the residuals hold. For the HP-filtered data, I also splitted the sample in three non-overlapping time periods, 1991- 1996, 1996- 2001, and 2001 - 2006. As dependent variables I use the cross-country correlation of hp-filtered GDP and investment, respectively, computed for the 20 quarters of each time period. I then regress GDP and investment correlation on the log of bilateral FDI linkages at the beginning of each time period, that is, FDI position in 1991, 1996, and 2001, respectively. For all these robustness checks, the findings are similar to the ones of the benchmark estimates in the main text. More FDI linkages are associated with higher investment correlations, and there is no statistical link between FDI linkages and GDP correlations (though the point estimate is positive).

Table 10: Bilateral FDI linkages and GDP synchronization, G7 country-pairs

Dependent Variable: GDP growth synchronization (annualized)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FDI/GDP	0.617**	0.108	0.317	0.346				
	(2.26)	(0.69)	(1.28)	(1.41)				
Trade/GDP				-0.421				
				(-0.74)				
FDI/Total FDI					0.447†	0.0763	0.207	0.222
					(1.57)	(0.47)	(0.80)	(0.86)
Trade/Total Trade								-0.172
								(-0.29)
Country-pair fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Country trends	Yes	No	Yes	Yes	Yes	No	Yes	Yes
R-squared (within)	0.179	0.343	0.365	0.366	0.172	0.343	0.363	0.363
Observations	315	315	315	315	315	315	315	315

Notes: The table reports panel (country-pair) fixed-effect coefficients estimated over the period 1991 to 2006 of the G7 countries plus country pairs involving Austria, Netherlands, Norway, and Sweden (in total, 40 country pairs). These are all countries for which bilateral FDI positions are available for all years. The dependent variable is minus one times the absolute value of the difference in quarterly growth rate of aggregate investment between country i and j in year t (the yearly estimate is obtained by averaging over the respective four quarterly estimates). In columns (1) - (4) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the previous year relative to the sum of the two countries' GDP in the previous year (denoted FDI/GDP). In columns (5) - (8) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the previous year relative to the sum of the two countries' total FDI Assets and FDI Liabilities in the entire world in the previous year (denoted FDI/Total FDI). All specifications also include the log of the two countries' GDP per capita, the log of the product of both countries' populations in the previous year, trade openness measured by Trade/GDP (in spec. (1) to (4)) or Trade/Total Trade (in spec. (5) to (8)), and the log of an index measuring industrial specialization, all lagged by one period (year). The specification in (4) includes an interaction term between FDI/GDP and a dummy variable (Dspec) that takes on the value one if the specialization index of a country pair is bigger than the median specialization of the sample and zero otherwise. Analogously it includes the same interaction term for Trade/GDP (not reported). Specification (8) includes an interaction term between FDI/Total FDI and a dummy variable (Dspec) that takes on the value one if the specialization index of a country pair is bigger than the median specialization of the sample and zero otherwise. The specifications in columns (1) and (5) include country-specific linear time-trends. The specifications in columns (2) and (6) include time fixed-effects. The specifications in columns (3), (4), (7), and (8) include time fixed-effects and country-specific linear time-trends. Standard errors adjusted for panel (country-pair) specific auto-correlation and heteroskedasticity and corresponding t-statistics are reported below the estimated coefficients. † denotes significance at the 85% confidence level, * denotes significance at the 90% confidence level, ** denotes significance at the 95% confidence level, *** denotes significance at the 99% confidence level. For a detailed data description see appendix A.

Table 11: Bilateral FDI linkages and investment correlations, hp-filtered data

Dependent Variable: cross-country correlation of hp-filtered investment								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FDI/GDP	0.230**	0.248***	0.214**	0.237**				
	(2.38)	(2.88)	(2.31)	(2.50)				
Trade/GDP				-0.594**				
				(-2.27)				
FDI/Total FDI					$0.167^{\dagger}$	0.193**	0.188*	0.243**
					(1.66)	(2.09)	(1.99)	(2.50)
Trade/Total Trade								-0.776***
								(-3.77)
Country-pair fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Country trends	Yes	No	Yes	Yes	Yes	No	Yes	Yes
R-squared (within)	0.396	0.367	0.461	0.475	0.388	0.357	0.459	0.490
Country-pairs	40	40	40	40	40	40	40	40
Observations	480	480	480	480	480	480	480	480

Notes: The table reports panel (country-pair) fixed-effect coefficients estimated over the period 1991 - 2006, using a balanced panel for 40 country-pairs for which bilateral FDI positions are available for all years. A list of included countries-pairs can be found in table ??. The dependent variable is the five-year average cross-country correlation of hp-filtered investment in country i and j averaged over the past 20 quarters. All right hand-side variables are lagged by five periods (years), that is, measured at the beginning of the rolling windo. In columns (1) - (4) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the initial year of the respective time period relative to the sum of the two countries' GDP in the in the initial year of the respective time period (denoted FDI/GDP). In columns (5) - (8) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the initial year of the respective time period relative to the sum of the two countries' total FDI Assets and FDI Liabilities vis-a-vis the entire world in the initial year of the respective time period (denoted FDI/Total FDI). All specifications also include the log of the two countries' GDP per capita, the log of the product of the two countries' population in the initial year of the respective time period, and the log of industrial specialization index. Specification (4) includes the log of the share of bilateral export and import flows between countries i and j in the initial year of the respective time period relative to the sum of the two countries' GDP in the initial year of the respective time period (Trade/GDP). Specification (8) includes the log of the share of bilateral export and import flows between countries i and j in the initial year of the respective time period relative to the sum of the two countries' total exports and imports in the initial year of the respective time period (Trade/Total Trade). The specifications in columns (1) and (5) include country-specific linear time-trends. The specifications in columns (2) and (6) include time fixed-effects. The specifications in columns (3), (4), (7), and (8) include time fixed-effects and country-specific linear time-trends. Standard errors adjusted for panel (country-pair) specific auto-correlation and heteroskedasticity and corresponding t-statistics are reported below. † denotes significance at the 85% confidence level, * denotes significance at the 90% confidence level, ** denotes significance at the 95% confidence level, *** denotes significance at the 99% confidence level. For a detailed data description see appendix A.

Table 12: Bilateral FDI linkages and output correlations, hp-filtered data

Dependent Variable: cross-country correlation of hp-filtered GDP								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FDI/GDP	-0.0267	0.0835	0.0299	0.0410				
	(-0.26)	(0.85)	(0.37)	(0.49)				
Trade/GDP				-0.282				
				(-1.27)				
FDI/Total FDI					-0.0114	0.122	0.0772	0.113
					(-0.11)	(1.39)	(0.96)	(1.29)
Trade/Total Trade								-0.505***
								(-2.80)
Country-pair fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Country trends	Yes	No	Yes	Yes	Yes	No	Yes	Yes
R-squared (within)	0.297	0.399	0.515	0.518	0.297	0.402	0.517	0.530
Country-pairs	40	40	40	40	40	40	40	40
Observations	480	480	480	480	480	480	480	480

Notes: The table reports panel (country-pair) fixed-effect coefficients estimated over the period 1991 - 2006, using a balanced panel for 40 country-pairs for which bilateral FDI positions are available for all years. A list of included countries-pairs can be found in table ??. The dependent variable is the five-year average cross-country correlation of hp-filtered GDP in country i and j averaged over the past 20 quarters. All right hand-side variables are lagged by five periods (years), that is, measured at the beginning of the rolling windo. In columns (1) - (4) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the initial year of the respective time period relative to the sum of the two countries' GDP in the in the initial year of the respective time period (denoted FDI/GDP). In columns (5) - (8) FDI integration is measured by the log of the share of the stock of bilateral Foreign Direct Investment Assets and Liabilities between countries i and j in the initial year of the respective time period relative to the sum of the two countries' total FDI Assets and FDI Liabilities vis-a-vis the entire world in the initial year of the respective time period (denoted FDI/Total FDI). All specifications also include the log of the two countries' GDP per capita, the log of the product of the two countries' population in the initial year of the respective time period, and the log of industrial specialization index. Specification (4) includes the log of the share of bilateral export and import flows between countries i and j in the initial year of the respective time period relative to the sum of the two countries' GDP in the initial year of the respective time period (Trade/GDP). Specification (8) includes the log of the share of bilateral export and import flows between countries i and j in the initial year of the respective time period relative to the sum of the two countries' total exports and imports in the initial year of the respective time period (Trade/Total Trade). The specifications in columns (1) and (5) include country-specific linear time-trends. The specifications in columns (2) and (6) include time fixed-effects. The specifications in columns (3), (4), (7), and (8) include time fixed-effects and country-specific linear time-trends. Standard errors adjusted for panel (country-pair) specific auto-correlation and heteroskedasticity and corresponding t-statistics are reported below. † denotes significance at the 85% confidence level, * denotes significance at the 90% confidence level, ** denotes significance at the 95% confidence level, *** denotes significance at the 99% confidence level. For a detailed data description see appendix A.

B.1 The financial autarky model with country-specific shocks only

This appendix presents - for completeness - the results on the financial autarky model and country-specific productivity shocks only. The purpose is to show that the main results on investment and GDP synchronization remain unaltered, even when abstracting from multinational-specific shocks under financial autarky. Figure 5 shows a similar plot with respect to investment synchronization as in the main text. In panel a), I show the benchmark results on the complete markets model with both shocks. Panel b) is new and shows the financial autarky model with productivity shocks only, panel c) and d) showing investment synchronization and FDI positions as functions of FDI openness parameter τ for the financial autarky economy with both shocks, hence repeating what is presented in the main text. It is evident from panel b) that the presence of technology capital only leads to the prediction of increased investment synchronization, even when financial markets are shut down and we abstract from shocks to multinational activity. The mechanisms behind this finding are exactly the same as outlined in the main text for the complete financial markets economies: When countries are more open to FDI, the returns of technology capital increase for both domestic and foreign multinationals, hence investment in technology capital increases in both countries. Because returns on all capital types are equalized within firms, multinationals increase investment in physical capital both at home and abroad, leading to an increase in investment co-movement.

Regarding GDP co-movement, figure 6 shows that the findings under financial autarky with productivity shocks only are very similar to the complete market model with productivity only.

Figure 5: FDI openness and Investment synchronization, details on the financial autarky model

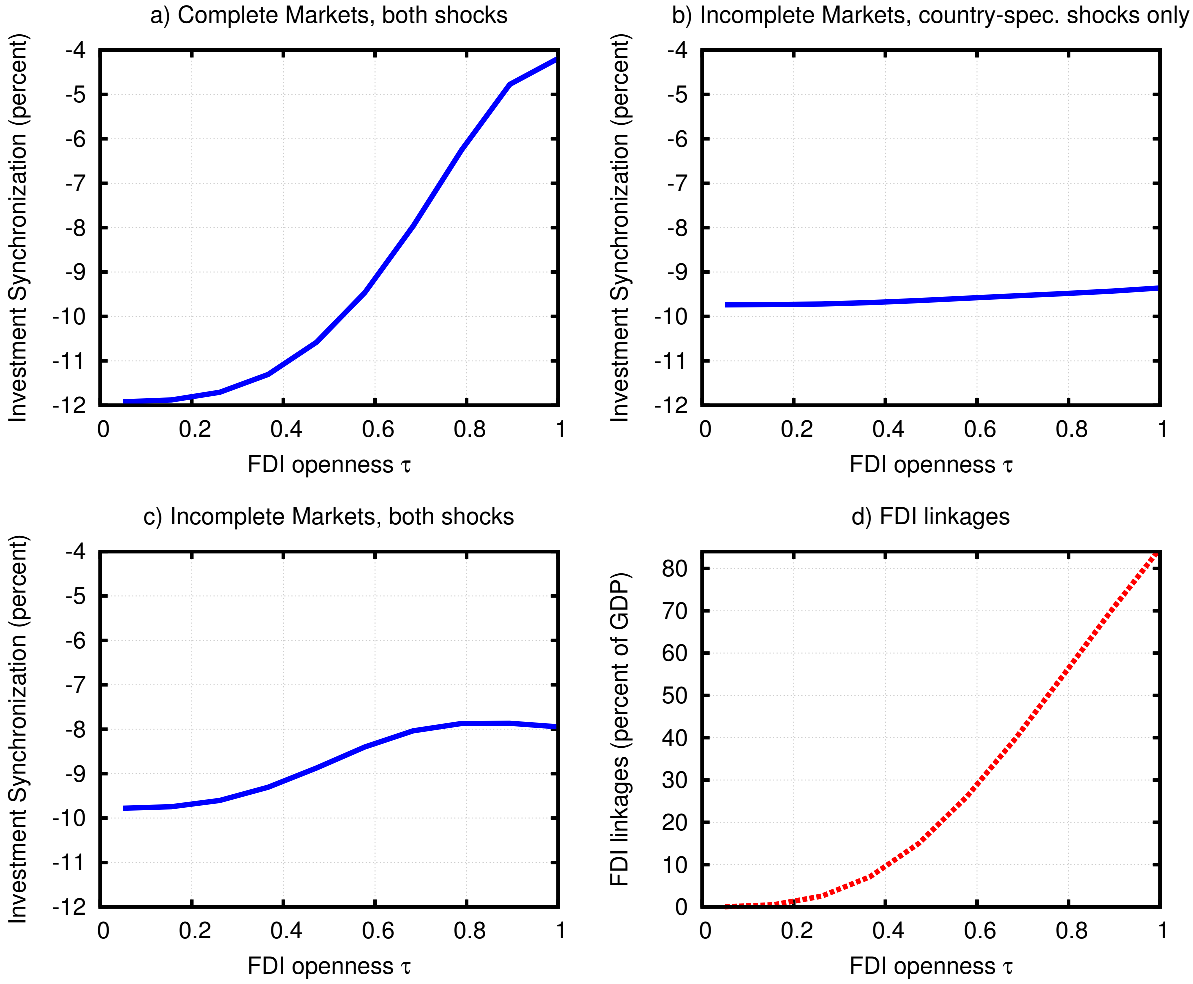
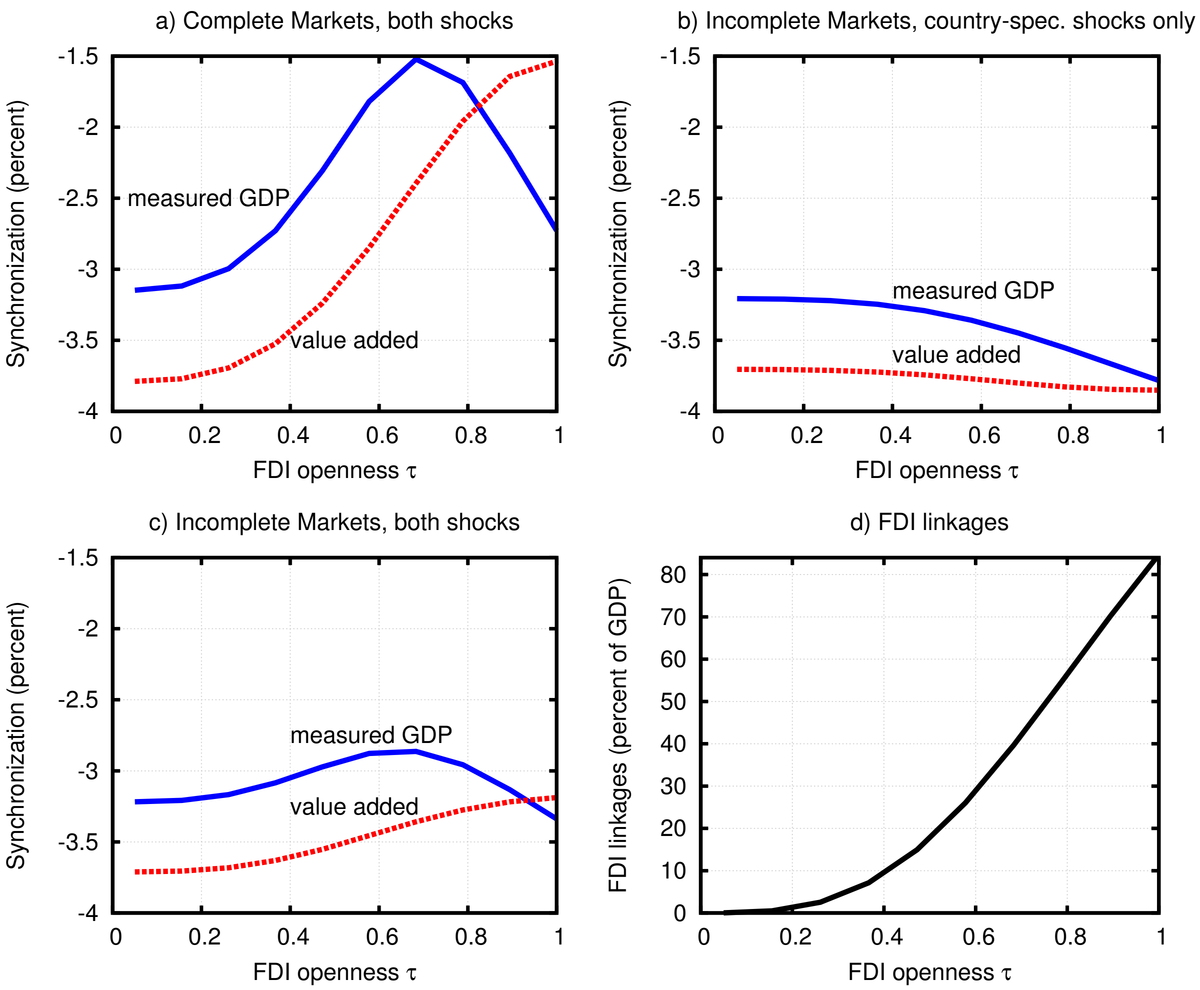


Figure 6: FDI openness and GDP synchronization, details on the financial autarky model



C Model details and additional results for the financial autarky case

C.1 Model Equations

In this subsection, I list the model equations, including the first order conditions of households and firms. Note that because the model is symmetric, the first order conditions for foreign firms are omitted.

Output in tradable good sector in the home country and relative price of intermediate good bundle

$$Y_t = A_t(k_{Tt}^{\theta} l_{Tt}^{1-\theta})^{\nu} X^{1-\nu}$$
$$P_t = (1-\nu)\frac{Y_t}{X_t}$$

Output on intermediate good sector in the home country

$$Y_{It} = \left[y_{dt}^{\eta} + (y_{ft}^{*})^{\eta} \right]^{\frac{1}{\eta}}$$

Optimality conditions w.r.t. labor for home firms

$$0 = (1-\theta)\nu Y_t - w_t l_{Tt}$$
$$0 = (1-\theta)(1-\phi)\eta P_t Y_{It}^{1-\eta} y_{dt}^{\eta} - w_t l_{dt}$$
$$0 = (1-\theta)(1-\phi)\eta P_t^{*}(Y_{It}^{*})^{1-\eta} y_{ft}^{\eta} - w^{*} t l_{ft}$$

Value of an additional unit of investment (i.e. Lagrange multiplier on investment accumulation equation) for home firms

$$V_{Tt} = \left[\chi_1 \left(\frac{i_{Tt}}{k_{Tt-1}}\right)^{-\psi}\right]^{-1}$$
$$V_{dt} = \left[\chi_1 \left(\frac{i_{dt}}{k_{dt-1}}\right)^{-\psi}\right]^{-1}$$
$$V_{ft} = \left[\chi_1 \left(\frac{i_{ft}}{k_{ft-1}}\right)^{-\psi}\right]^{-1}$$
$$V_{Mt} = \left[\chi_1^m \left(\frac{i_{Mt}}{M_{t-1}}\right)^{-\psi_m}\right]^{-1}$$

Optimality conditions with respect to investment, home firms

$$V_{Tt}k_{Tt+1} = \beta E_t \left\{\frac{\lambda_{t+1}}{\lambda_t}\Big(\theta\eta Y_{t+1} - i_{Tt+1} + V_{Tt+1}k_{Tt+2}\Big)\right\}$$
$$V_{dt}k_{dt+1} = \beta E_t \left\{\frac{\lambda_{t+1}}{\lambda_t}\Big(\theta(1-\phi)\eta P_t Y_{It}^{1-\eta} y_{dt}^{\eta} - i_{dt+1} + V_{dt+1}k_{dt+2}\Big)\right\}$$
$$V_{ft}k_{ft+1} = \beta E_t \left\{\frac{\lambda_{t+1}}{\lambda_t}\Big(\theta(1-\phi)\eta P_t^* (Y_{It}^*)^{1-\eta} y_{ft}^{\eta} - i_{ft+1} + V_{ft+1}k_{ft+2}\Big)\right\}$$
$$V_{Mt}M_{t+1} = \beta E_t \left\{\frac{\lambda_{t+1}}{\lambda_t}\left[\phi\eta\Big(P_t Y_{It}^{1-\eta} y_{dt}^{\eta} + P_t^* (Y_{It}^*)^{1-\eta} y_{ft}^{\eta}\Big) - i_{Mt+1} + V_{Mt+1}M_{t+2}\right]\right\}$$

Domestic and foreign production by home owned multinationals

$$y_{dt} = e^{z_t} M_t^{\phi} \left(k_{dt}^{\theta} l_{dt}^{1-\theta}\right)^{1-\phi}$$
$$y_{ft} = \tau e^{z_t} M_t^{\phi} \left(k_{ft}^{\theta} l_{ft}^{1-\theta}\right)^{1-\phi}$$

Total dividends households in the home country receive

$$d_t = (Y_t - w_t l_{Tt} - i_{Tt}) + (P_t Y_{It}^{1-\eta} y_{dt}^{\eta} - w_t l_{dt} - i_{dt}) + (P_t^* (Y_{It}^*)^{1-\eta} y_{ft}^{\eta} - w_t^* l_{ft} - i_{ft}) - i_{Mt}$$

Capital accumulation

$$k_{jt+1} = (1-\delta)k_{jt} + \left[\frac{\chi_1 \left(\frac{i_{jt}}{k_{jt}} \right)^{1-\psi}}{1-\psi} + \chi_2 \right] k_{jt} \qquad j = T, d, f$$

$$M_{t+1} = (1-\delta_m)M_t + \left[\frac{\chi_1^m \left(\frac{i_{Mt}}{M_t} \right)^{1-\psi_m}}{1-\psi_m} + \chi_2^m \right] M_t$$

Analoguous for foreign firms. Domestic and foreign households

$$\begin{aligned}
\lambda_t &= U_1(C_t, \bar{L} - L_t) \\
\lambda_t^* &= U_1(C_t^*, \bar{L} - L_t^*) \\
0 &= U_2(C_t, \bar{L} - L_t) + \lambda_t w_t \\
0 &= U_2(C_t^*, \bar{L} - L_t^*) + \lambda_t^* w_t^*
\end{aligned}$$

Labor market clearing

$$\begin{aligned}
L_t &= l_{Tt} + l_{dt} + l_{ft}^* \\
L_t^* &= l_{Tt}^* + l_{dt}^* + l_{ft}
\end{aligned}$$

Goods market clearing

$$Y_t + Y_t^* = C_t + C_t^* + i_{Tt} + i_{Tt}^* + i_{dt} + i_{ft} + i_{dt}^* + i_{ft}^* + i_{Mt} + i_{Mt}^*$$

International financial markets:

a) Complete financial markets

$$\lambda_t = \lambda_t^*$$

b) Financial autarky

$$C_t = w_t L_t + d_{Tt} + d_{Mt}$$

C.2 Deterministic steady state

The system of equations in the deterministic steady state for two complete open economies $\tau = 1$ are given by

$$\frac{1-\beta(1-\delta)}{\nu\theta\beta} = \frac{Y}{K_1} \qquad \frac{1-\beta(1-\delta)}{\nu\theta\beta} = \frac{Y^*}{K_1^*}$$
$$\frac{1-\beta(1-\delta)}{(1-\phi)\theta\eta\beta} = PY_2^{1-\eta}\frac{y_d^\eta}{k_d} \qquad \frac{1-\beta(1-\delta)}{(1-\phi)\theta\eta\beta} = PY_2^{1-\eta}\frac{(y_f^*)^\eta}{k_f^*}$$
$$\frac{1-\beta(1-\delta)}{(1-\phi)\theta\eta\beta} = P^*(Y_2^*)^{1-\eta}\frac{y_f^\eta}{k_f} \qquad \frac{1-\beta(1-\delta)}{(1-\phi)\theta\eta\beta} = P^*(Y_2^*)^{1-\eta}\frac{(y_d^*)^\eta}{k_d^*}$$
$$\frac{1-\beta(1-\delta_m)}{\phi\eta\beta} = \frac{PY_2^{1-\eta}y_d^\eta + P^*(Y_2^*)^{1-\eta}y_f^\eta}{M} \qquad \frac{1-\beta(1-\delta_m)}{\phi\eta\beta} = \frac{P^*(Y_2^*)^{1-\eta}(y_d^*)^\eta + PY_2^{1-\eta}(y_f^*)^\eta}{M^*}$$

$$wL_1 = (1-\theta)\nu Y \qquad wL_1^* = (1-\theta)\nu Y^*$$
$$wl_d = (1-\theta)(1-\phi)\eta PY_2^{1-\eta}y_d^\eta \qquad wl_f^* = (1-\theta)(1-\phi)\eta PY_2^{1-\eta}(y_f^*)^\eta$$
$$w^*l_d^* = (1-\theta)(1-\phi)\eta P^*(Y_2^*)^{1-\eta}(y_d^*)^\eta \qquad w^*l_f = (1-\theta)(1-\phi)\eta P^*(Y_2^*)^{1-\eta}y_f^\eta$$
$$L = l_f^* + l_d + L_1 \qquad L^* = L_1^* + l_d^* + l_f$$
$$K = k_f^* + k_d + K_1 \qquad K^* = K_1^* + k_d^* + k_f$$
$$Y = (K_1^\theta L_1^{1-\theta})^\nu Y_2^{1-\nu} \qquad Y^* = ((K_1^*)^\theta (L_1^*)^{1-\theta})^\nu (Y_2^*)^{1-\nu}$$
$$P = (1-\nu)Y \qquad P^* = (1-\nu)Y^*$$

$$c + c^* + \delta(K + K^*) + \delta_m(M + M^*) = Y + Y^*$$

Note that when $\tau = 1$ both countries are identical, therefore all home and foreign quantities and prices are identical, so I will omit for now the asterisk. One can show that $(k_d + k_f)/K_1 = (l_d + l_f)/L_1 = \xi$, with $\xi = (1-\phi)(1-\nu)\eta/\nu$. Also note that the parameters of the utility function are set so that $L = 1$ in steady state, so that we obtain the following system of equation for technology, physical capital and aggregate output:

$$M = \frac{\phi\beta(1-\nu)\eta}{1-\beta(1-\delta_m)}Y$$
$$K = \frac{(1-\phi)\theta\beta(1-\nu)\eta}{1-\beta(1-\delta)}Y$$
$$Y = 2^{1-\nu}\left(\frac{1}{1+\xi}\right)^{\nu}\left(\frac{\xi}{1+\xi}\right)^{(1-\phi)(1-\nu)} K^{\theta(\nu+(1-\nu)(1-\phi))}$$

We can combine these equations and obtain the steady state values for technology and physical capital

$$
\begin{aligned}
M &= \zeta_1^{\frac{\theta(\nu+(1-\nu)(1-\phi)}{\zeta_3}} \zeta_2^{\frac{1}{\zeta_3}} \\
K &= \zeta_1 M
\end{aligned}
$$

with

$$
\begin{aligned}
\zeta_1 &\equiv \frac{\theta(\nu + (1-\nu)(1-\phi)\eta)}{\phi(1-\nu)\eta} \frac{1-\beta(1-\delta_m)}{1-\beta(1-\delta)} \\
\zeta_2 &\equiv \frac{\phi\beta(1-\nu)\eta}{1-\beta(1-\delta_m)} 2^{1-\nu} \left(\frac{1}{1+\xi}\right)^{\nu} \left(\frac{\xi}{1+\xi}\right)^{(1-\phi)(1-\nu)} \\
\zeta_3 &\equiv 1 - \phi(1-\nu) - \theta(\nu + (1-\phi)(1-\nu)).
\end{aligned}
$$

All the other quantities follow by plugging in these values in the respective equations. Because financial market structure only in the economy with uncertainty, the deterministic steady state is the same whether or not financial markets are complete.