Vertical Linkages, International Trade, and Macroeconomic Dynamics

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Chapter 1

Introduction

The greatest improvement in the productive powers of labour [...] seem to have been the effects of the division of labour.

As it is the power of exchanging that gives occasion to the division of labour, so the extent of this division must always be limited by the extent of that power, or, in other words, by the extent of the market.
Adam Smith (1776), An Inquiry into the Nature and Causes of the Wealth of Nations, Volume I, Book I, Chapters I and III.

1.1 Plan of the dissertation

In the days of Adam Smith, the various stages required to produce a good were usually concentrated in close geographical proximity. While the efficiency gains derivable from splitting production processes into separate tasks had been unveiled, the division of labor generally proceeded locally. The costs of transporting parts and components from one production facility to another, particularly across borders, were prohibitively high for most commodities.

Nowadays, more than two centuries later, the picture has changed dramatically. In fact, the division of labor has become truly international and production chains increasingly stretch over several national borders. To reap the benefits of the division of labor, firms no longer need to concentrate production in a single factory. They are now able to "fine-tune" the locational pattern of individual production stages to international factor prices (Kohler 2004*b*). Each stage can be located where production is cheapest, so that countries increasingly specialize in particular "tasks" rather than entire production chains (Grossman and Rossi-Hansberg 2008*b*). As a result, intermediate goods and services are being shipped across the globe, either at arm's length or in the form of intra-firm trade by multinational companies. In brief, the past two decades or so have witnessed the rise of *vertical*

linkages, i.e. cross-country links established by international production chains.[1] Empirical evidence documenting the growing importance of vertical linkages will be presented in Section 1.2.

The sweeping changes in the international division of labor have been facilitated by a decline in distance costs. Technological advances in transportation and communication have greatly reduced the frictions associated with a spatially fragmented production process. In particular, new forms of telecommunication, such as the internet and electronic mail, have facilitated the coordination and monitoring of distant production activities. Faster transport, e.g. in the form of airborne trade and faster vessels, has made it viable to ship fragments "just in time" from one factory to the other at reasonable cost (Hummels 2001). Hummels and Schaur (2012) reckon that each day in transit is equivalent to an ad-valorem tariff of 0.6 to 2.3 percent and that trade in parts and components is particularly time-sensitive. At the same time, economic liberalization has provided a powerful catalyst for the expansion of vertical linkages. Many countries have torn down barriers to international trade, cut red tape, and embraced foreign direct investment.

vertical linkages ——— Chapters 2 & 3 ——— international trade

Chapters 4 & 5   Chapter 5

macroeconomic dynamics
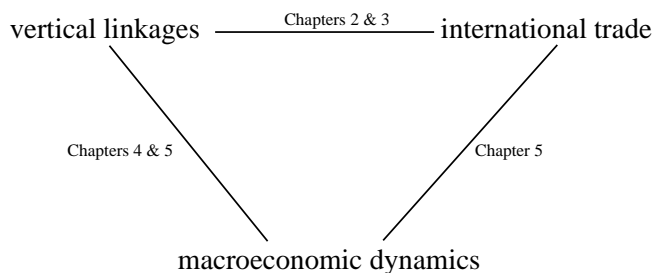
Figure 1.1 Synopsis of the dissertation

The expansion of vertical linkages is not only transforming the international division of labor, but has profound consequences for international trade and macroeconomic dynamics, too. This is, in a nutshell, the main theme of this dissertation (see Figure 1.1 for a synopsis). The first part of the dissertation, i.e. Chapter 2, takes the perspective of international trade theory. More specifically, the chapter puts forward a novel mechanism explaining how vertical linkages have contributed to the staggering long-run growth in international trade over recent decades. The second part of the dissertation shifts the focus to international macroeconomics. Chapter 3 demonstrates theoretically that more extensive vertical linkages raise the short-run volatility and cross-country synchronization of trade flows, while Chapter 4 develops a DSGE model with truly endogenous vertical linkages. The

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[1]I will use the terms *vertical fragmentation* or *international fragmentation of production* to refer to the general process resulting in vertical linkages. By contrast, *offshoring* describes the corresponding internationalization strategy of an individual firm.

findings of Chapter 3 complement the work by Kose and Yi (2001, 2006), who showed that vertical linkages also foster output co-movement. However, vertical linkages are not the only form of international integration that has progressed rapidly over the past two decades. Against this backdrop, Chapter 5 seeks to disentangle the various channels involved in international business cycle synchronization, including trade and financial linkages. Chapter 6 brings together the main findings from the previous chapters.

In greater detail, *Chapter 2* is devoted to the longer-term consequences of vertical linkages for international trade. The chapter proposes a novel mechanism that helps explain the surge in world trade over the last two decades: the export-magnification effect of offshoring. It is shown analytically in a general equilibrium model with heterogeneous firms that a fall in variable offshoring costs boosts trade in differentiated final goods through an intra-industry reallocation of resources towards the more productive firms. More specifically, lower barriers to offshoring reduce the average costs of inputs for offshoring firms and allow more firms to source cheap foreign intermediates, which improves firm-level price competitiveness. This, in turn, translates into higher export quantities of incumbent exporters (intensive margin) and the entry of new exporters (extensive margin). The increase in final goods trade comes on top of the boost to trade in intermediates. Hence the mechanism proposed in Chapter 2 is consistent with the fact that the share of intermediate goods in international trade has remained broadly stable over recent years (see Section 1.2). Chapter 2 also sheds some light on the determinants of the sourcing decision at the firm level. In the model, firms are free to source their inputs at home or abroad, in both cases at arm's length. While foreign intermediates are cheaper than domestic ones, they are associated with variable and fixed offshoring costs. Due to this trade-off, only the more productive firms find it optimal to purchase foreign intermediates.

Chapter 3 enters the realm of international macroeconomics. It explores theoretically how vertical linkages affect the short-term dynamics of international trade flows. As a matter of fact, world trade has not only increased tremendously over recent decades, but has also become more volatile relative to production and income. A case in point is the collapse of world trade in 2008-09. At that time, international trade flows declined dramatically, also relative to output. It is widely held that the international fragmentation of production has been a key driver of the increased volatility of trade. The chapter provides a rigorous theoretical foundation for this idea. Based on a minimal International Real Business Cycle (IRBC) model with vertical linkages, it is shown how closer vertical linkages between countries raise the volatility of international trade. The chapter also demonstrates numerically that the cross-country synchronization of trade flows rises as vertical linkages become more important. This finding dovetails nicely with the fact that the trade

collapse of 2008-09 was not only exceptionally severe but also highly synchronized across countries. In brief, the model not only helps explain the longer-term increase in the volatility of trade, but is also consistent with key stylized facts of the global downturn of 2008-09.

Chapter 4 takes the macroeconomic analysis of vertical linkages - or offshoring, for that matter - one step further. More specifically, I build a Dynamic Stochastic General Equilibrium (DSGE) model in which both the intensive and extensive margins of offshoring are endogenous. The *extensive* margin of offshoring refers to the range of production stages located offshore, while the *intensive* margin relates to the quantity of a given intermediate produced offshore (Kohler 2004*b*). Standard micro-founded macro models typically treat the extensive margin as exogenous. More specifically, they typically rely on Armington aggregators to bundle domestic and foreign inputs. A fixed weight is assigned to each component and, in the case of changes in relative input prices, firms vary only the relative quantities of these bundles. While this strategy is understandable on the grounds of modeling parsimony, it is unclear how the shutdown of the extensive margin of offshoring affects the international transmission of shocks. To shed some light on this issue, Chapter 4 presents a medium-scale DSGE model with truly endogenous vertical linkages. In the model, firms are free to decide on both the range of intermediates to be imported from abroad (extensive margin) and the quantity of each imported intermediate (intensive margin). In the most general model variant, the extensive margin is pinned down by a trade-off between task-specific offshoring costs and task-specific technology. There are no fixed costs. The underlying methodology is in the spirit of the continuous goods model by Dornbusch, Fischer and Samuelson (1977). The dynamics of the full-fledged model are then compared with those of the same model where the extensive margin of offshoring is exogenously fixed. As it turns out, the dynamics of the two model variants are very similar. Moreover, the extensive margin hardly fluctuates over the business cycle, even if firms can costlessly shift back and forth between domestic and foreign sourcing. Hence the findings suggest that fixing the extensive margin of offshoring is largely inconsequential in standard DSGE models. These findings also justify ex post the modeling approach chosen in Chapter 3, where vertical linkages are modeled using a standard Armington aggregator.

Chapter 5 retains the focus on the link between international linkages and macroeconomic dynamics. More specifically, it studies empirically how economic integration affects international business cycle synchronization. The underlying empirical model captures not only vertical linkages, but also financial ties and other relevant channels for the international transmission of shocks. While vertical linkages have increased tremendously over the past two decades, economic integration has also progressed in other areas, particularly in financial markets.

Drawing on a large cross-section of countries, the chapter disentangles the role of the various channels, including trade and financial linkages as well as the similarity in sectoral specialization. One of the novelties of this chapter compared with the existing literature is that it takes into account cross-country linkages established by FDI. This is important, since foreign direct investment is one of the salient features of the recent wave of globalization (Bordo, Eichengreen and Irwin 1999). The results confirm that output co-movement is higher for country pairs with closer trade linkages and similar patterns of sectoral specialization. By contrast, there is no conclusive evidence of a direct relationship between bilateral financial linkages and output correlation. That said, the results suggest that financial integration spurs business cycle synchronization indirectly by raising the similarity in sectoral specialization. I also find that FDI and portfolio investment have very similar effects on international output co-movement.

Chapter 6 brings together the main findings from the previous chapters and presents a synopsis of the relationship between vertical linkages, international trade, and macroeconomic dynamics.

1.2 The rise of vertical linkages: Empirical evidence

Since vertical linkages take center stage throughout this dissertation, this section presents a brief overview of the vast body of empirical evidence documenting their growing importance.

To start with, case studies provide an illustrative, though incomplete, picture of the international fragmentation of production. Consider the iPhone. Although the product is sold by a U.S. based firm, Apple, only a few tasks, such as research and development as well as marketing, are based in the United States. The production process itself largely takes place overseas, with final assembly being located in China. Yet, of the estimated USD 178.96 wholesale costs, only around 3.6 percent reflect Chinese value added, according to Xing and Detert (2010). The bulk of the parts and components assembled in China are imported from abroad, with around 33.9 percent stemming from Japan, 16.8 percent from Germany, 12.8 percent from South Korea and 6.0 percent from the United States. For instance, the display module and touch screen are produced in Japan, the application processor is manufactured in South Korea, the baseband comes from Germany and other parts from the United States. If anything, the preceding calculation underestimates the true extent of the international fragmentation of the production process, since the parts and components imported from, say, Germany are also likely to embody foreign value added. Nevertheless, the example illustrates the

global scope and high degree of specialization characterizing the web of vertical linkages that are permeating the world economy.

Turning to aggregate indicators of vertical linkages, a widely used measure is the share of imported intermediates in total intermediate inputs used in the manufacturing sector. The data plotted in Figure 2.1 are based on OECD input-output tables for 29 OECD economies at two points in time, namely the mid-1990s and the mid-2000s. While the extent to which intermediates are imported varies substantially across countries, the share of imported intermediates increased in the vast majority of OECD countries over this period. Particularly large increases in the share of imported inputs were recorded in the Central and Eastern European economies, such as the Czech Republic, Slovakia, and Slovenia, which have increasingly been integrated into European production networks.

Numerous studies based on input-output tables confirm the expansion of vertical linkages (e.g. Campa and Goldberg 1997, Feenstra 1998, Feenstra and Hanson 1996). Buoyant international trade along the value chain also shows up in data on trade in parts and components (e.g. Yeats 1998) and processing trade (e.g. Egger and Egger 2005).[2] Furthermore, Bernard, Jensen, Redding and Schott (2007) reckon that the high correlation between the industries with high shares of importing firms and those with high shares of exporters can be seen as an indirect indication of the importance of vertical linkages.

Imported inputs are not only used in the production of goods and services absorbed domestically. In fact, exports also increasingly embody foreign value added and fragments often cross national borders several times before reaching their final destination. Hummels, Ishii and Yi (2001) show that the use of imported inputs in the production of exports ("vertical specialization") rose substantially between 1970 and 1990 and explains around one-third of the growth in overall export growth over this period. Breda, Cappariello and Zizza (2008) come to similar conclusions for a set of European economies. In countries that are heavily involved in international production chains - such as Mexico, China, and other emerging economies in Asia - foreign value added nowadays accounts for around 40 percent of gross exports, as illustrated by Figure 1.3. By the same token, the vertical fragmentation of production creates challenges for the measurement of trade. International trade flows are traditionally recorded in gross terms. In the presence of vertical linkages and multiple border crossings, these statistics can become an unreliable measure of the value added by individual countries along the

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[2]Trade in parts and components refers to product groups in the Standard International Trade Classification (SITC) that are unambiguously used as inputs for the production of other products. The category is essentially a subset of intermediate goods trade, as it excludes items for which the distinction between intermediate and final use is not clear-cut. Processing trade involves imports of foreign inputs for the production of a good which is then re-exported. Processing trade often benefits from preferential tariffs.
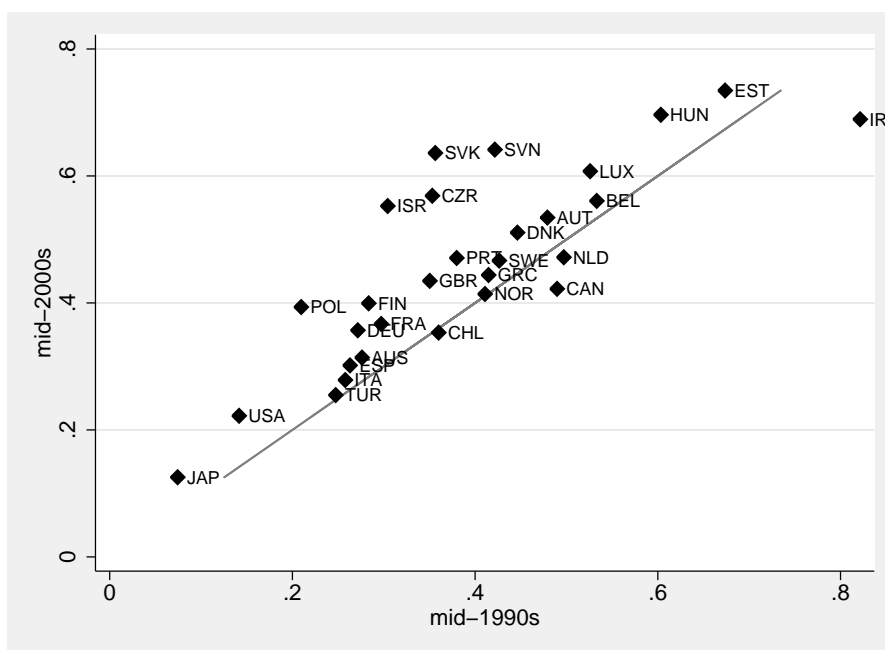
Figure 1.2 The growth in vertical linkages over time. The figure shows the share of imported intermediates in total intermediates used in the manufacturing sector for 29 OECD countries (mid-1990s vs. mid-2000s). Data missing for New Zealand, Mexico, South Korea, and Switzerland. The straight line shows the 45°-line. Source: OECD (STAN database).

production chain.[3]

Conventional wisdom has it that the vertical fragmentation of production has also led to an increase in the share of intermediate goods in total world trade. However, this is not borne out by the facts. On the one hand, trade in intermediates has rapidly increased over recent years and accounts for a significant share of global trade. The World Trade Organization estimates that, in 2008, the share of intermediate manufactured products in non-fuel world trade was around 40 percent (WTO 2009). Miroudot, Lanz and Ragoussis (2009) reckon that trade in intermediate inputs makes up 56 percent of world trade in goods and 73 percent of global trade in services. They also find that the average annual growth rate of trade in intermediate inputs between 1995 and 2006 was around 6 percent for goods and 7 percent for services in volume terms. On the other hand, trade in final goods expanded in parallel to trade in intermediates. As a consequence, the share of intermediate goods in total merchandize trade did not increase over this period

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[3]A number of methodologies have recently been developed to partially overcome this problem. They typically combine information from input-output tables with data on gross trade flows. See, for instance, Koopman, Powers, Wang and Wei (2010) and Johnson and Noguera (forthcoming).
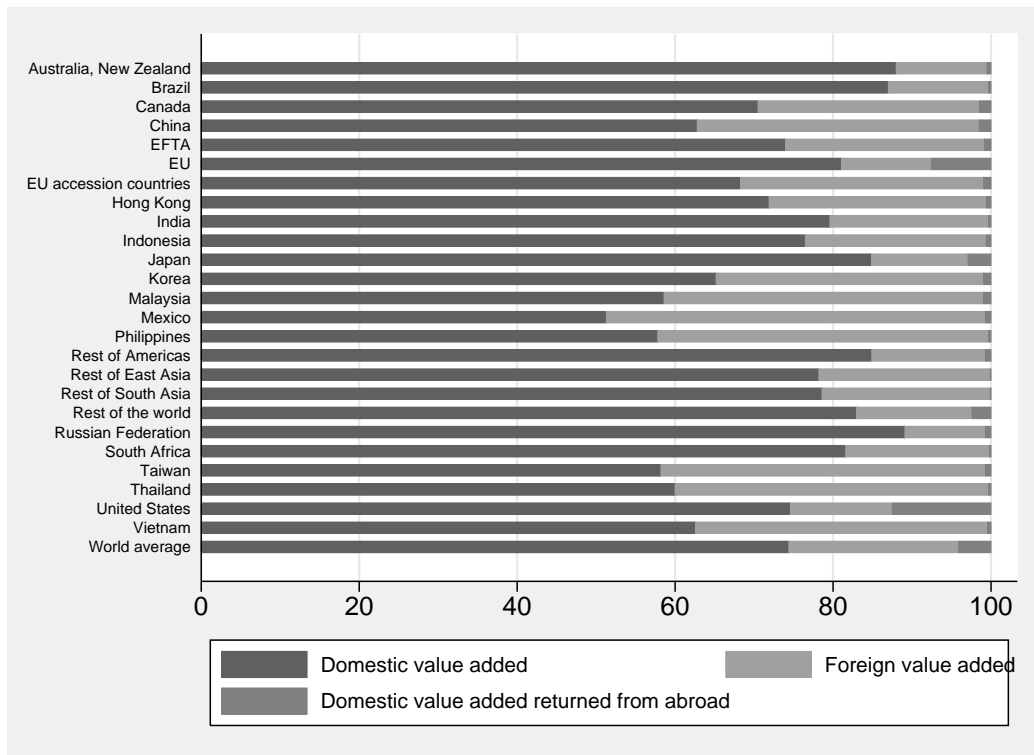
Figure 1.3 Decomposition of gross exports into value added components. For various countries and regions, the figure presents a breakdown of gross exports into (i) domestic value added, (ii) foreign value added and (iii) domestic value added returned from abroad. Source: Adapted from Koopman et al. (2010).

(Hummels et al. 2001, Miroudot et al. 2009). This is consistent with evidence from extra-EU15 trade, where imports and exports of intermediate goods were less dynamic in volume terms than consumption and capital goods (see Figure 1.4). How this stylized fact can be reconciled with an important role of vertical linkages in explaining the longer-term growth in international trade will be discussed in Chapter 2.

While vertical linkages have indeed become international, proximity still matters (Leamer 2007). Production chains often retain a regional focus. A case in point are the close linkages between the United States and the Mexican maquiladoras. Bergin, Feenstra and Hanson (2007) report that almost half of Mexico's exports are produced in these offshoring industries, the bulk of which is exported to the United States. Similarly, Europe has witnessed the emergence of complex regional production networks. Falk and Wolfmayr (2008) find that EU "core" countries increasingly import material inputs from low-wage countries, particularly from those

(a) Imports   (b) Exports
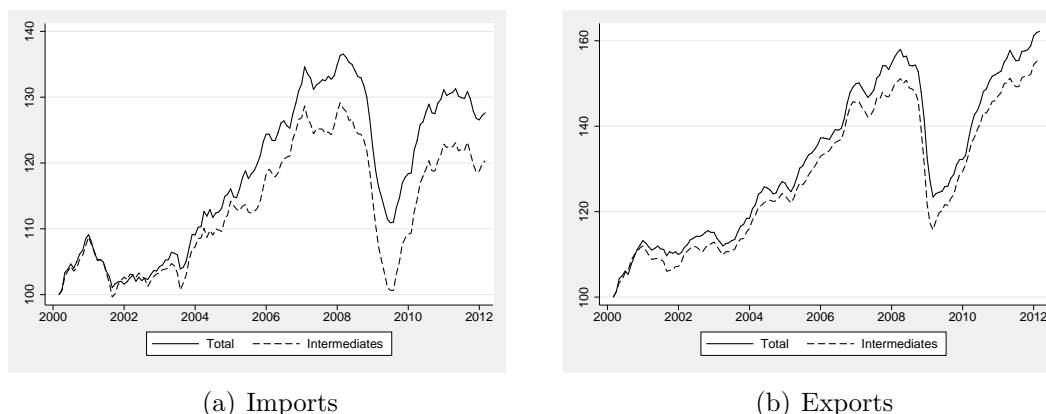
Figure 1.4 Breakdown of extra-euro area trade. The figure shows extra-euro area import and export volumes of goods by Broad Economic Categories (BEC). Indices, March 2000=100; 3-month moving averages. Source: Eurostat (External Trade Statistics).

in Central and Eastern Europe. Since this often involves multinational firms from "core" Europe and assembly plants in Central and Eastern Europe, intra-firm trade looms large. For instance, intra-firm trade accounts for around 20 percent of Austrian exports to Eastern Europe and around 70 percent of its imports from these countries; estimates for Germany are lower, around 10 percent for exports and 20 percent for imports (Marin 2006).[4]

However, vertical linkages not only tie together high-income countries with lower-income countries. In fact, Grossman and Rossi-Hansberg (2008a) reckon that trade in tasks predominantly takes place between similar countries and build a model to explain this phenomenon. In the model, countries with similar relative factor endowments find it optimal to trade tasks among each other, since individual tasks generate local spillovers. Here, factor price differentials are no longer the main driver of offshoring. The importance of vertical linkages among similar countries is also illustrated by the fact that the bulk of intermediates imported by advanced economies originate in other advanced economies (Miroudot et al. 2009). Notwithstanding this, the birth of regional core-periphery blocks has often led to a substitution away from imports from high-income countries, without raising the share of imported intermediates in total intermediates used (Egger and Egger 2005, Molnar, Pain and Taglioni 2007).

The sourcing decision of an individual firm has not only a locational but also an organizational dimension. A firm willing to source inputs from abroad can either purchase them from non-related parties (offshore outsourcing) or from foreign affil-

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[4]Buch and Kleinert (2006) provide an in-depth analysis of the patterns of German FDI in Central and Eastern Europe.

iates. Available evidence suggests that both sourcing modes are quantitatively important. Imports of intermediates at arm's length are the dominant international sourcing mode for smaller, less productive firms and tend to be more important in industries with high capital and skill intensity (Bernard et al. 2007, Kohler and Smolka 2011, Tomiura 2007). At the same time, importers of foreign inputs tend to be more productive than firms sourcing their inputs domestically.

The largest and most productive firms, however, typically source their inputs from foreign affiliates. As a result, intra-firm trade nowadays accounts for a significant share of international trade. For the United States, data from the Census Bureau show that the overall share of related-party trade in U.S. imports has slightly increased over recent years and currently stands at 49 percent.[5] However, as Bernard, Jensen, Redding and Schott (2010) point out, the aggregate figures conceal considerable variation across trading partners and industries. For instance, around 70 percent of U.S. imports from Japan and Mexico occur between related parties, whereas only 2 percent of imports from Bangladesh represent intra-firm trade.

While intra-firm trade accounts for a large fraction of total U.S. trade, the trade activities of U.S. multinationals with non-related parties have increased at a faster pace than trade of U.S. multinationals with related parties over recent years (see Figure 1.5).[6] Furthermore, even if a multinational firm owns foreign affiliates that are vertically linked with the parent (according to industry-level input-output tables), this does not necessarily give rise to physical trade flows between the affiliate and the parent. In fact, Ramondo, Rappoport and Ruhl (2011) find that affiliates that are, in principle, located upstream or downstream of their U.S. parent tend to sell their products to unrelated parties in the country of operation. They argue that the bulk of actual intra-firm trade is concentrated on a small number of large affiliates.

The coexistence of foreign sourcing at arm's length and vertical integration within the boundaries of multinational firms has inspired a burgeoning literature on the organizational dimension of the sourcing decision.[7] In the context of this dissertation, however, the organizational dimension of the sourcing decision is of secondary order. After all, both sourcing modes establish vertical linkages between countries and thereby open up a channel for the transmission of shocks across borders. Moreover, both sourcing modes allow firms to tap cheap foreign inputs and both are associated with international trade in intermediates, either within

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[5]Loosely speaking, related-party trade in the Census Bureau data includes all transactions between a U.S. importer or exporter and a foreign entity where either party owns, directly or indirectly, at least 10 percent (exports) or 6 percent (imports) of the other party.

[6]See also Zeile (2003).

[7]See, for instance, Antràs and Helpman (2004, 2008) who highlight contractual frictions affecting the sourcing decision of individual firms.
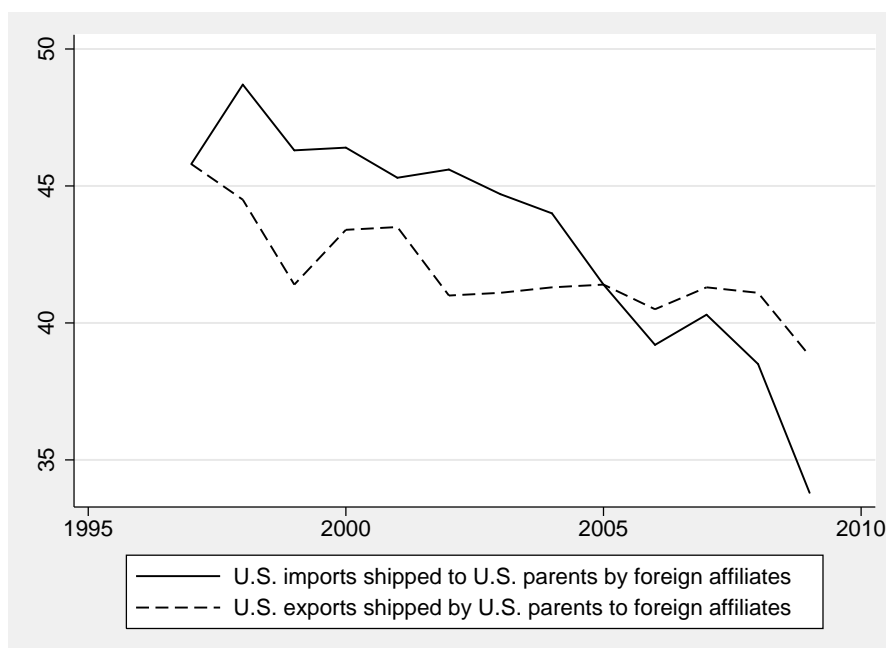
Figure 1.5 Share of intra-firm trade in the total trade activities of U.S. multinationals. Source: Bureau of Economic Analysis.

or beyond the boundaries of the sourcing firm. Therefore, I will mainly focus on the locational dimension of the sourcing decision, i.e. whether a particular input is sourced domestically or from abroad.

Data on foreign direct investment (FDI) provide an alternative view on the empirical relevance of vertical linkages. Global FDI stocks have increased almost fivefold since the early 1980s and now stand at roughly 30 percent of world GDP. Empirical evidence suggests that this wave of FDI has been dominated by horizontal FDI, where multinational firms set up or acquire foreign affiliates whose products are roughly similar to those the firm produces for the home market. This form of FDI is usually driven by market access motives ("proximity-concentration trade-off"). Vertical FDI, where firms geographically fragment the production process to take advantage of international factor price differentials, is generally thought to be of secondary order.[8] Looking at the internationalization strategies of German multinationals, Buch, Kleinert, Lipponer and Toubal (2005) find that cost-saving motives are clearly dominated by market-access motives. This is consistent with evidence from other countries, including the United States (e.g. Brainard 1993, Markusen 1995, 2004).

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[8]Helpman (1984) and Helpman and Krugman (1985) develop an influential theoretical framework for the analysis of vertical FDI. For a synthesis of the various motives for FDI, see Yeaple (2003*a*) and Grossman, Helpman and Szeidl (2006).

Notwithstanding this, a number of recent papers have argued that vertical FDI could be more prevalent than previously thought. Alfaro and Charlton (2009), for instance, demonstrate that vertical FDI is often misclassified as horizontal FDI at standard aggregation levels. Hanson, Mataloni and Slaughter (2001) show that the cross-country variation in intra-firm trade is consistent with a vertical motive for FDI. Looking at the structure of U.S. FDI, Yeaple (2003b) finds that, in industries with high (low) skilled-labor intensities, FDI tends to flow into countries where skilled labor is relatively abundant (scarce), consistent with an important role for vertical FDI driven by comparative advantage.

In summary, there is ample empirical evidence that vertical linkages have been rapidly expanding over recent years and have become a salient feature of the recent wave of globalization. In line with Adam Smith's hypothesis (as quoted at the beginning of this chapter), lower distance costs have effectively enlarged the "extent of the market" open to individual firms and thereby promoted a finer international division of labor.[9]

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[9]Kohler (2004a) outlines the conditions under which this process is associated with a welfare gain or "fragmentation surplus".

Chapter 2

Vertical linkages and the long-term growth in international trade[†]

2.1 Introduction

The past two decades have seen globalization proceed at an ever finer level of resolution (see Chapter 1). Production is increasingly sliced up into separate tasks that can be traded internationally (Grossman and Rossi-Hansberg 2008*b*). As a result, more and more firms are engaged in offshoring: they either import intermediates from offshore affiliates or purchase foreign intermediates at arm's length. This "high-resolution globalization" (Baldwin 2006, 2008) has been paralleled by a surge in world merchandize trade. The global trade-to-GDP ratio almost doubled between the mid-1980s and 2008, from 14 to 27 percent. While the ratio dropped precipitously amid the global downturn of 2008-09, it quickly rebounded thereafter. The longer-term increase in the ratio of trade to manufacturing production was even sharper (Irwin 2005).

  This chapter proposes a novel mechanism linking the rise of offshoring and the intensification of world trade, based on a general equilibrium model with heterogeneous firms. It is shown analytically that a fall in offshoring costs boosts trade in differentiated final goods through an intra-industry reallocation of resources towards the more productive firms: the *export-magnification effect of offshoring.* In a nutshell, lower barriers to offshoring allow more domestic firms to source cheap foreign intermediates and reduce the input costs of offshoring firms, which improves firm-level price competitiveness. This, in turn, translates into higher

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export quantities of exporters (intensive margin) and the entry of new exporters (extensive margin), thereby fostering trade in final goods.

The analysis rests on a three-sector multi-country general equilibrium model with heterogeneous firms in the vein of Melitz (2003). There are many symmetric advanced economies and one "workbench country" (think of China or the Central and Eastern European countries). Ricardian comparative advantages determine the equilibrium trade patterns: the advanced economies import cheap intermediates from the workbench country in return for a homogeneous consumption good. At the same time, they trade differentiated products among each other to satisfy consumers' love of variety. The export-magnification effect describes the increase in final goods trade *among the advanced economies* resulting from a drop in offshoring costs vis-à-vis the *workbench country.* Thus, neither income growth nor lower trade costs between the advanced economies drive the rise in bilateral trade between these countries.

Crucially, each firm in the differentiated good sector is free to decide not only whether to export or not (export decision) but also whether to purchase intermediates at home or abroad (offshoring decision). Both exporting and offshoring is subject to variable and fixed costs. Therefore, only the larger, more productive firms engage in offshoring: the cost reductions generated by offshoring are proportional to the amount of intermediates used, whereas the fixed costs are identical for all firms. Likewise, only the most productive firms simultaneously engage in both offshoring and exporting. This self-selection of firms into exporting and sourcing modes is indeed broadly consistent with empirical evidence (Tomiura 2007).

Following the description of the equilibrium with trade in final goods and offshoring, the chapter studies analytically the consequences of closer integration of the workbench country into the global economy - modeled as a fall in variable offshoring costs. Not surprisingly, inter-industry trade in homogeneous intermediate and final goods intensifies. More remarkably, given that trade costs in differentiated final goods between the advanced economies have remained unchanged, closer integration of intermediate goods markets also boosts exports of final goods at both the intensive and extensive margin. Access to cheaper intermediates from abroad allows highly productive firms to increase their export quantities and additional firms manage to become exporters. The ensuing reallocation of resources toward the more productive firms raises the average firm efficiency in the differentiated final good sector. This, in turn, lowers the consumption price level and raises real wages, thereby leading to a long-run welfare gain.

Of course, the idea that offshoring (or the vertical fragmentation of production, for that matter) partly accounts for the surge in world trade is not new. That said, the mechanism proposed in this chapter differs considerably from those in the existing theoretical literature, which has largely relied on models with representative

firms. Most prominently, Yi (2003) demonstrated in a homogeneous firms setup that multiple border crossings of intermediate goods render trade more responsive to changes in trade costs, which brings down the trade elasticity required to explain the actual increase in world trade. By their very nature, representative firm models cannot capture the intra-industry reallocation of resources described in this chapter, which generates an increase in final goods trade in response to lower offshoring costs, over and above the intensification in intermediates trade.

The model is related to an extensive offshoring literature. The concept of offshoring used here is in the tradition of the theory of international fragmentation (Deardorff 1998, 2001, Jones 2000, Kohler 2004*b*). Hence, the profitability of offshoring solely depends on the interplay of comparative advantages and offshoring costs. All imperfections in contracting and matching that feature so prominently in other approaches to offshoring (Antràs 2003, Feenstra and Hanson 2005, Grossman and Helpman 2005) are excluded.

The model is also related to a few papers featuring heterogeneous firms models with trade in intermediates. Kasahara and Lapham (2008) study the decision to import and export in an extended Melitz framework. However, the paper does not analyze analytically the comparative static trade effects of a marginal drop in offshoring costs. Moreover, the model setup differs considerably from that presented here. Since all countries are identical in the model by Kasahara and Lapham (2008), it best describes trade among a group of fairly similar advanced or emerging economies respectively. Fixed import costs are firm-specific and subject to shocks. Moreover, importers use all available varieties of domestic and foreign intermediates, since there are increasing returns to variety in the production function. Furthermore, Bas (2009) constructs a multi-sector model with heterogeneous firms and endogenous markups where the imported input intensity and import tariffs vary across industries. It is shown empirically that industries with lower import tariffs or higher import dependence generate more exporters and higher export sales than other industries. By contrast, the focus of this chapter is on the within-industry trade effects of changes in offshoring costs over time. In a related paper, Kugler and Verhoogen (2008) use an extended Melitz model to study the hypothesis that input quality and plant productivity are complementary in generating output quality. In contrast to the theoretical framework proposed in this chapter, trade takes place between two symmetric countries and there can be quality differences in both intermediate and final goods.

The remainder of this chapter is structured as follows. Section 2.2 presents the motivation for the theoretical analysis, while Section 2.3 introduces the theoretical framework. Section 2.4 studies the effects of lower offshoring costs on individual firms and the overall economy. This is complemented by other comparative statics, including the effects of lower export costs. Section 2.5 concludes.

2.2   The issue

International trade has increased tremendously over the last two decades. Neither income growth nor reductions in trade costs and tariffs can explain this phenomenon exhaustively. Time series regressions would usually apply a globalization time trend to account for this "unexplained" growth in trade (Ca'Zorzi and Schnatz 2007, Murata, Turner, Rae and LeFouler 2000). An impression of the increase in trade is given in Figure 2.1, which presents the developments in EU15 trade since the 1990s. The cumulated increase in trade over this period was much stronger than the increase in the GDP of the EU15, which implies an increase in the trade-to-GDP ratio. In standard trade models, these large increases of trade relative to GDP cannot be sufficiently explained by reductions in trade costs and tariffs alone. While trade costs and tariffs have indeed fallen over recent decades (see, for instance, Hummels 2007), the elasticity of trade with respect to trade costs that is needed to generate the observed trade response is implausibly large in standard models (Yi 2003).
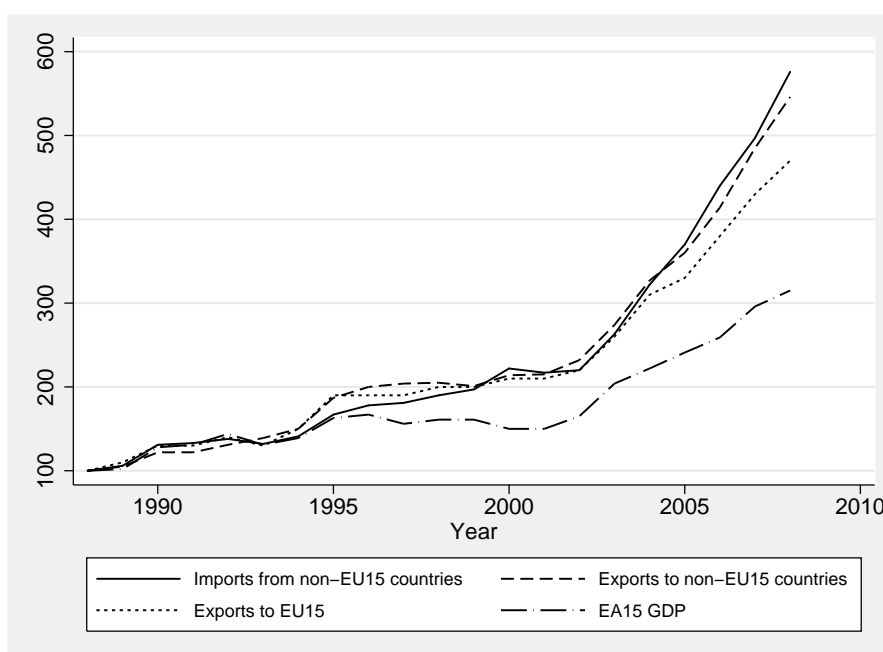
Figure 2.1 EU15 GDP and manufacturing export values by partner region (indices, 1988=100). Source: OECD (STAN database), own composition.

An obvious candidate to resolve this puzzle is the vertical fragmentation of production, which gained momentum in the mid-1980s, in parallel to the surge in world trade. Related explanations have so far been centered around the fact that intermediate goods often cross borders several times (with little value added

at a particular production stage) before arriving at their final destination. The most basic argument highlights that, in practice, trade is measured in gross terms, whereas GDP is measured in terms of value added. This inflates the trade-to-GDP ratio, partially rendering the surge in world trade a statistical artifact.

However, if this were the whole story, one would expect intermediates trade to increase significantly over time relative to trade in final goods. This is not borne out by the data: while trade in intermediates has increased at a rapid pace over the last two decades, trade in final goods has followed virtually in lockstep. As a result, the share of intermediate goods in total merchandize trade has not increased over this period (Hummels et al. 2001, Miroudot et al. 2009). This is consistent with evidence from extra-EU15 trade, where intermediate goods have been less dynamic in volume terms than final goods since 2000 (see Section 1.2).

Against this backdrop, this chapter develops a novel mechanism that (i) reserves an important role for the vertical fragmentation of production in explaining the surge in world trade and (ii) is consistent with a stable trade share of intermediates. In essence, it is shown analytically how intensified trade in intermediates (or offshoring, for that matter) boosts trade in final goods in a heterogeneous firms setup.

Consistent with the narrative proposed here, exports are higher in OECD countries where offshoring is more prevalent. This point is illustrated by Figure 2.2, which plots a country's exports (scaled by GDP) in relation to the ratio of intermediate goods in total intermediates used in the production of that particular country. The relationship is clearly positive. This positive relationship survives at the five percent level of significance if year and country fixed effects control for unobserved effects (and country size).

2.3   The model

This section develops the theoretical framework underlying the analysis. The world consists of $n+1$ perfectly symmetric countries ("advanced economies") and another country, called the "workbench country" (W). The advanced economies host three sectors. In the first sector (Y), a homogeneous final good is produced under perfect competition. This homogeneous good is consumed by households and traded without any costs between countries. Firms in the second sector (I) produce a homogeneous intermediate good under perfect competition. In the third sector (X), firms combine labor and the intermediate good to produce a differentiated consumption good. This good is traded only between the advanced economies to satisfy consumers' love of variety. The sole factor of production, labor, is mobile between sectors but not between countries. Hence there is just one wage rate within each country. However, labor productivity may vary across sectors.
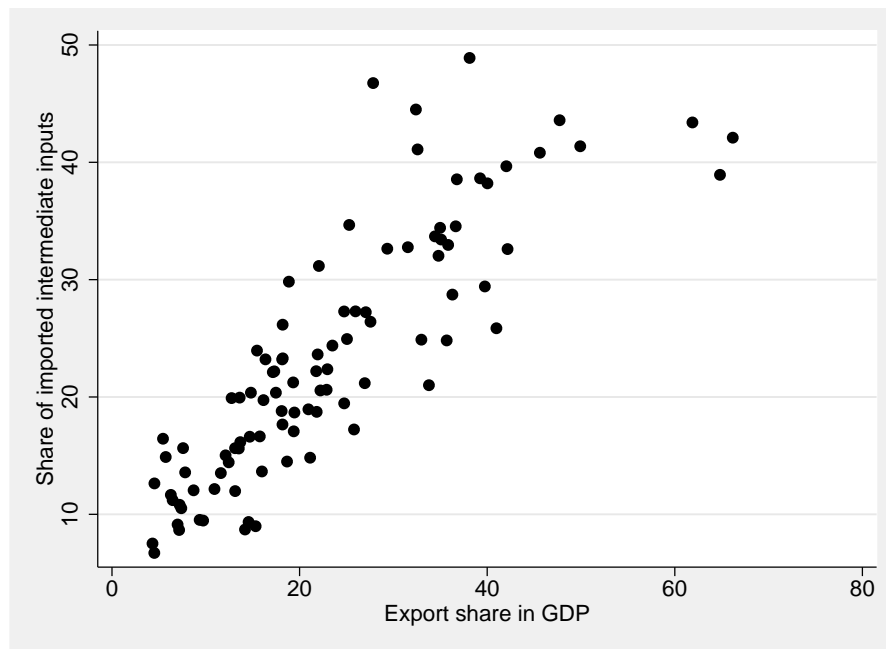
Figure 2.2 Manufacturing exports over GDP and share of imported intermediates in total intermediate goods used. For all available OECD countries, the figure plots the share of imported intermediate inputs in total intermediates used against the exports-to-GDP ratio (pooled data for mid-1990s, early 2000s, mid-2000s). Source: OECD (STAN database).

Country W is not directly involved in producing or trading the differentiated final good. Its main purpose is to serve as a supplier of intermediate goods for the other countries. In essence, this separation allows to maintain the assumption that all countries trading the differentiated final good are symmetric.

Final good producers in the differentiated good sector differ in terms of productivity in the vein of Melitz (2003). Crucially, they can purchase intermediates either from domestic or from foreign suppliers. The latter case refers to *offshoring*. The price of intermediates from country W is lower than that of domestic intermediates. The lower price results from the Ricardian comparative advantage in the production of intermediates (relative to the production of the homogeneous final good) that W enjoys by assumption. In addition, offshoring requires fixed costs. Think of the resources necessary to establish an office overseas for coordination purposes. The existence of fixed offshoring costs triggers self-selection of firms into the sourcing modes. Only firms with high productivity manage to take benefit of cheap foreign intermediates, because they can bear the burden of higher fixed costs.

While, in the model, trade in intermediates is at arm's length, it would be

straightforward to write the model in terms of intra-firm trade (involving vertical FDI), without any change in the main findings.

2.3.1 Households

Households in all advanced economies have identical preferences. In the following, I describe only one of the $n+1$ symmetric countries, called the home country (H). Unless stated otherwise, the other countries go through analogously.

The representative household has Cobb-Douglas preferences over the homogeneous final good, Y, and the bundle of differentiated goods, X:

$$U = X^\beta Y^{1-\beta} \qquad (0 < \beta < 1). \tag{2.1}$$

The X-bundle, in turn, is a CES aggregator over the mass of available varieties, which is endogenous and denoted by Ω:

$$X = \left[\int_{\omega \in \Omega} x(\omega)^\rho \, \mathrm{d}\,\omega \right]^{\frac{1}{\rho}}. \tag{2.2}$$

Here, $x(\omega)$ is consumption of a single variety $\omega \in \Omega$. Varieties are substitutes, with $\rho \equiv (\sigma - 1)/\sigma$ and σ denoting the elasticity of substitution ($\sigma > 1$).

The price index of the differentiate good, P_X, is then given by:

$$P_X = \left[\int_{\omega \in \Omega} p(\omega)^{1-\sigma} dk \right]^{1/(1-\sigma)}. \tag{2.3}$$

Here, $p(\omega)$ is the consumer price of variety ω.

Total expenditures, E, are made up of expenditures on good X and Y: $E = E_X + E_Y$. Cobb-Douglas preferences imply that consumers spend a constant expenditure share β on the differentiated good. Expenditures on a single variety ω are given by: $e(\omega) = (p(\omega)/P_X)^{1-\sigma} E_X$.

2.3.2 The homogeneous goods sectors

Each advanced economy hosts three sectors. Two of them are characterized by perfect competition between producers of homogeneous goods: the final good Y and the intermediate good I. In these two sectors, labor is the only input for production. Labor productivity, denoted by φ_Y and φ_I respectively, differs across industries, but is the same for all firms within each industry. Since labor is mobile between sectors, there is a unique wage rate w. The same is true for the other countries. Sector Y's *raison d'être* is to pin down these wage rates.

Both homogeneous goods sectors are characterized by a production technology that is linear in labor:

$$Y = \varphi_Y L_Y \tag{2.4}$$

$$I = \varphi_I L_I. \tag{2.5}$$

The two homogeneous goods are also produced in the workbench country. Sector-specific labor productivities in the workbench country, φ_Y^w and φ_I^w, differ from those in the advanced economies. In the following, it is assumed that all countries (including the workbench country) have a positive output of both Y and I. Hence there is no complete specialization.

Good Y is the numeraire so that $p_Y = 1$. Perfect competition implies $p_Y = 1 = w/\varphi_Y$ and $p_Y^w = w^w/\varphi_Y^w$. Notice that superscript w stands for the workbench country W. Since good Y is traded without costs between countries, prices are equalized: $p_Y = p_Y^w = 1$. This pins down the wage rates: $w = \varphi_Y$ and $w^w = \varphi_Y^w$. As the intermediate good sector is also perfectly competitive, factory prices are determined as

$$p_I^d = \frac{w}{\varphi_I} = \frac{\varphi_Y}{\varphi_I}, \qquad p_I^w = \frac{w^w}{\varphi_I^w} = \frac{\varphi_Y^w}{\varphi_I^w}, \tag{2.6}$$

where the superscript d indicates the intermediate goods produced by *domestic* firms in the advanced countries. Trade in intermediates involves variable trade costs τ_I (with $\tau_I > 1$). Assuming iceberg costs, the c.i.f. price of the foreign intermediate good is $p_I^{off} = \tau_I p_I^w$. If the c.i.f. price of foreign intermediates were higher than the price of domestic intermediates, no domestic firm would find it profitable to source intermediates from abroad. Therefore, the following assumption is critical:

Assumption A.1 *Foreign's comparative advantage in the production of good I (relative to production of good Y) is large enough to make up for the trade costs τ_I. In other words, the c.i.f. price of foreign intermediates, p_I^{off}, is lower than the price of domestic intermediates, p_I^d:*

$$\frac{\varphi_Y/\varphi_Y^w}{\varphi_I/\varphi_I^w} > \tau_I > 1 \qquad \Leftrightarrow \qquad \frac{p_I^{off}}{p_I^d} < 1.$$

This assumption on comparative advantages determines the equilibrium pattern of trade between each advanced economy and the workbench country. It requires trade costs τ_I not to be too large. Under this assumption, the advanced economies import intermediate goods from the workbench country and export the homogeneous final good Y in exchange. In addition, the advanced economies trade the differentiated final goods among each other. Although they do not trade the homogeneous good Y among each other, they share the same price $p_Y = 1$, since they all trade Y freely with W.

2.3.3 Differentiated good sector

In the third sector, heterogeneous firms produce a differentiated final good (X) under Dixit-Stiglitz-type monopolistic competition. Production requires domestic labor and an intermediate good. The production technology is of Cobb-Douglas type, with α representing the importance of the intermediate input ($0 < \alpha < 1$).

Crucially, as in Melitz (2003), firms differ in their productivity φ, which is drawn at entry from a common distribution $g(\varphi)$.[1] Furthermore, firms are free to source their intermediates either from domestic or foreign suppliers. Hence the second key element determining a firm's production costs (next to its productivity draw) is the price p_I^k that the firm pays for intermediate inputs:

$$p_I^k = \begin{cases} p_I^d & \text{if the firm sources domestic intermediates} \\ p_I^{off} & \text{if the firm sources foreign intermediates.} \end{cases} \tag{2.7}$$

It is convenient to define a summary measure - called *firm efficiency* - that combines a firm's productivity level φ and its unit cost of intermediate inputs: $\phi^k = \varphi/(p_I^k)^\alpha$. As will become obvious, the optimal sourcing decision and therefore the firm-specific sourcing cost of intermediates depend on firm productivity: $p_I^k = p_I^k(\varphi)$. More specifically, more productive firms will opt for foreign intermediates, whereas less productive firms will have to content themselves with domestic ones. (The conditions under which this partitioning of firms holds will be described below.) This implies that firm efficiency is itself a function of the firm's productivity level. For the sake of simplicity, firms will be indexed by ϕ^k, bearing in mind that firm efficiency is ultimately determined by firm-specific productivity. Note that offshoring reduces the marginal costs of a manufacturing firm similarly to an increase in productivity.

Since the production technology is of Cobb-Douglas type, variable costs are given by $c(\phi^k) = w^{1-\alpha}/\phi^k$. In this setting of monopolistic competition, every firm sets its price $p(\phi^k)$ optimally by multiplying its marginal costs with a fixed markup factor of $1/\rho$. Hence revenues from domestic sales are given by:

$$r_H(\phi^k) = \left[\frac{w^{1-\alpha}}{\rho\phi^k}\right]^{1-\sigma} \frac{E_X}{P_X^{1-\sigma}}. \tag{2.8}$$

Production of the final good requires fixed overhead costs f_p in terms of labor. Hence, if a firm sources its intermediates domestically ($k = d$), its profits from sales at home are given by:

$$\pi_H(\phi^d) = \frac{r_H(\phi^d)}{\sigma} - f_p w. \tag{2.9}$$

---

[1]It is assumed that the $(\sigma - 1)$th uncentered moment of $g(\varphi)$ is finite. This will ensure that the productivity of the average firm is finite.

If a firm purchases foreign intermediates ($k = off$), it faces additional fixed costs of offshoring, f_I. Profits can then be written as:

$$\pi_H(\phi^{off}) = \frac{r_H(\phi^{off})}{\sigma} - (f_p + f_I)w. \tag{2.10}$$

In both cases, profits rise with firm efficiency ϕ^k and aggregate demand, whereas they depend negatively on the domestic wage rate and fixed costs.

Firms whose productivity is too low to recoup the fixed costs f_p have to leave the market immediately after drawing their productivity. Let the minimum productivity a firm must have drawn to survive be denoted by $\widehat{\varphi}_{min}$. Firms with productivity $\varphi = \widehat{\varphi}_{min}$ will make zero profits. This implies that the minimum productivity is given by:

$$\widehat{\varphi}_{min} = \frac{w^{1-\alpha}\left(p_I^d\right)^\alpha}{\rho P_X}\left(\frac{\sigma f_p w}{E_X}\right)^{\frac{1}{\sigma-1}}. \tag{2.11}$$

Notice that $r_H(\phi^d(\widehat{\varphi}_{min})) = \sigma f_p w$. For the time being, it is taken as given that the marginal firm entering the market neither exports nor engages in offshoring. Hence it is possible to derive the minimum efficiency: $\widehat{\phi}_{min} = \widehat{\varphi}_{min}/(p_I^d)^\alpha$.

Every firm is free to source its intermediates from abroad. By assumption A.1, the price of foreign intermediates is lower than that of domestic ones. Nevertheless, the least productive firms cannot afford to engage in offshoring. Since they sell less than their competitors, the lower variable cost associated with offshoring cannot make up for the fixed cost f_I. Therefore, offshoring is only profitable for firms passing a certain threshold productivity. Let this productivity level for which a firm is indifferent between domestic sourcing and offshoring be denoted by $\widehat{\varphi}_{off}$. Then:

$$\begin{aligned}
\widehat{\varphi}_{off} &= \left[\left(\frac{p_I^{off}}{p_I^d}\right)^{\alpha(1-\sigma)} - 1\right]^{\frac{1}{1-\sigma}} \frac{w^{1-\alpha}(p_I^d)^\alpha}{\rho P_X}\left(\frac{\sigma f_I w}{E_X}\right)^{\frac{1}{\sigma-1}} \\
&= \widehat{\varphi}_{min}\left(\frac{f_I}{f_p}\right)^{\frac{1}{\sigma-1}}\left[\left(\frac{p_I^{off}}{p_I^d}\right)^{\alpha(1-\sigma)} - 1\right]^{\frac{1}{1-\sigma}}.
\end{aligned} \tag{2.12}$$

The corresponding firm efficiency is: $\widehat{\phi}_{off} = \widehat{\varphi}_{off}/(p_I^{off})^\alpha$.

As already indicated, it is assumed that only the most productive firms find it profitable to export. In addition to f_p and f_I, they have to bear the fixed cost of exporting, f_{ex}. At the same time, however, these firms are able to lift their sales by serving foreign consumers. Recall that country H trades the differentiated good only with the n symmetric advanced economies. Owing to the symmetry

assumption, a firm will either serve all n export markets or none at all. Total profits are therefore given by:

$$\pi(\phi^{off}) = \pi_H(\phi^{off}) + n\pi_F(\phi^{off})$$
$$= \left(1 + n\tau^{1-\sigma}\right) r_H(\phi^{off})/\sigma - (f_p + f_I + nf_{ex}) w. \qquad (2.13)$$

Here, τ denotes iceberg trade costs associated with the final good ($\tau > 1$).

The cutoff productivity level $\widehat{\varphi}_{ex,off}$ for which an offshoring firm is indifferent between exporting and non-exporting is given by:

$$\widehat{\varphi}_{ex,off} = \tau \frac{w^{1-\alpha}(p_I^{off})^\alpha}{\rho P_X} \left(\frac{\sigma f_{ex} w}{E_X}\right)^{\frac{1}{\sigma-1}}$$
$$= \widehat{\varphi}_{min} \, \tau \left(\frac{f_{ex}}{f_p}\right)^{\frac{1}{\sigma-1}} \left(\frac{p_I^{off}}{p_I^d}\right)^\alpha. \qquad (2.14)$$

Notice that $\widehat{\phi}_{ex,off} = \widehat{\varphi}_{ex,off}/(p_I^{off})^\alpha$.

As indicated above, it is taken taken as given that $\widehat{\varphi}_{min} < \widehat{\varphi}_{off} < \widehat{\varphi}_{ex,off}$. The following assumptions, together with assumption A.1, ensure that this partitioning of firms indeed holds true (see Section 2.6.1 in the appendix).

Assumption A.2 *The comparative advantage of the workbench country in producing the intermediate good, adjusted for distance costs, i.e. $\tau_I \varphi_Y^w \varphi_I/\varphi_I^w \varphi_Y = p_I^{off}/p_I^d$, is in the interval $(\min\{\tilde{p}_1, \tilde{p}_2\}, \max\{\tilde{p}_1, \tilde{p}_2\})$, where*

$$\tilde{p}_1 \equiv \left(\frac{f_p}{f_p + f_I}\right)^{\frac{1}{\alpha(\sigma-1)}}, \qquad \tilde{p}_2 \equiv \left(1 - \frac{f_I}{f_{ex}\tau^{\sigma-1}}\right)^{\frac{1}{\alpha(\sigma-1)}}.$$

To ensure that the minimum productivity $\widehat{\varphi}_{ex,off}$ is larger than the minimum productivity $\widehat{\varphi}_{off}$, as assumed above, the following assumption is needed, which has a similar counterpart in Melitz (2003):

Assumption A.3 *The threshold levels are ordered such that: $\tilde{p}_2 > \tilde{p}_1$. That requires $f_p + f_I < f_{ex}\tau^{\sigma-1}$.*

In essence, the competitive edge of foreign suppliers of intermediates must be large enough to make offshoring profitable for some domestic firms. At the same time, it cannot be too large, because otherwise all firms would engage in offshoring. Higher variable trade costs τ enlarge the interval of admissible relative prices p_I^{off}/p_I^d. The same is true for higher fixed costs f_p and higher fixed export costs f_{ex}, whereas the interval shrinks with higher fixed offshoring costs f_I. If f_I were zero, no level of variable offshoring costs τ_I would be large enough to restore the assumed ordering

of firms, since all firms would self-select into the same sourcing mode. Violation of assumptions A.1 through A.3 would give rise to a different partitioning of firms in equilibrium. Offshoring could then turn out to be profitable for no firm, all firms, or only exporters.

The partitioning of firms assumed above ($\hat{\varphi}_{min} < \hat{\varphi}_{off} < \hat{\varphi}_{ex,off}$) is entirely motivated by empirical evidence. The first inequality should be uncontroversial in the light of overwhelming evidence that firms involved in international trade tend to be more productive than "non-traders". It is also a well-established fact that firms involved in both importing and exporting are generally more productive than firms that only import or only export.[2] This justifies the assumption that the most productive firms choose to import and export.

It is less obvious which of the two "incomplete" internationalization strategies - i.e. only exporting or only offshoring - requires higher productivity. In the model, the two strategies cannot occur simultaneously in equilibrium. If offshoring is less demanding in terms of firm productivity, for instance, the export-only strategy will always be dominated. Looking at data on Japanese manufacturing firms, Tomiura (2007) finds that firms engaged in international outsourcing are less productive than firms that only export (and both have higher productivity than non-traders), although the productivity differential between outsourcers and exporters is relatively small. This is consistent with the assumptions on the ordering of cut-off productivities.

While there is also a growing literature comparing the characteristics of importing and exporting firms, it is of limited use for the purposes of this chapter. The main reason is that most of the studies do not differentiate between imports of intermediates and final goods (including capital and consumption goods). For instance, Castellani, Serti and Tomasi (2010) find that Italian firms which are engaged only in importing generally have higher productivity than firms involved in exporting only. This is consistent with evidence for Belgium (Muuls and Pisu 2009) and Hungary (Altomonte and Békés 2010). Castellani et al. (2010) caution, however, that their findings may partly reflect imports of capital goods and sectoral composition effects, since the incidence of firms only involved in importing is higher for capital intensive industries. Moreover, the evidence from this literature on the pecking order of importing and exporting firms is far from clear-cut. In contrast to the studies previously mentioned, McCann (2009) finds that, in Ireland, exporters-only are significantly more productive than importers-only. For China, Manova and Zhang (2009) show that there are more small firms (which tend to be less productive) among importers than among exporters. Andersson, Lööf and Johansson (2008) show for Sweden that the "productivity premium" is of similar

---

[2]For a survey of the related empirical literature, see Bernard, Jensen, Redding and Schott (2011), Wagner (2007, 2011). See also Bernard, Jensen and Schott (2009).

magnitude for exports and imports. Due to data constraints, all these studies cannot capture the import content of domestic intermediates used by domestic firms.

Against this backdrop, it appears reasonable to stick to the assumption that offshoring is less demanding in terms of productivity ($\widehat{\varphi}_{off} < \widehat{\varphi}_{ex,off}$). However, it will be discussed below how a different ordering of cut-off productivities would affect the main results.

2.3.4 Aggregation

In this model, all aggregate variables can be expressed in terms of appropriate industry-level averages. It is convenient to use weights reflecting the relative output shares of individual firms. Differences in the relative output shares of two individual firms will be driven by differences in firm efficiency: $x(\phi')/x(\phi'') = (\phi''/\phi')^{\sigma}$. Therefore, cross-firm averages based on output shares must take into account different input costs (as long as the firms do not share the same sourcing mode). Against this backdrop, let $\widetilde{\phi}$ denote the average efficiency of all domestic firms and $\widetilde{\phi}_t$ the average efficiency of all firms active in country H (including foreign exporters):

$$
\widetilde{\phi} = \left[\int_0^{\infty} \left(\phi^k(\varphi) \right)^{\sigma-1} \mu(\varphi)\, \mathrm{d}\varphi \right]^{\frac{1}{\sigma-1}}
$$

$$
= \left\{ \frac{1}{M} \left[M_d \widetilde{\phi}_d^{\sigma-1} + M_{off} \widetilde{\phi}_{off}^{\sigma-1} + M_{ex,off} \widetilde{\phi}_{ex,off}^{\sigma-1} \right] \right\}^{\frac{1}{\sigma-1}} \tag{2.15}
$$

$$
\widetilde{\phi}_t = \left\{ \frac{1}{M_t} \left[M \widetilde{\phi}^{\sigma-1} + n M_{ex,off} \left(\tau^{-1} \widetilde{\phi}_{ex,off} \right)^{\sigma-1} \right] \right\}^{\frac{1}{\sigma-1}}. \tag{2.16}
$$

Here, $\mu(\varphi) = g(\varphi)/[1 - G(\widehat{\varphi}_{min})]$ is the equilibrium productivity distribution. Furthermore, $\widetilde{\phi}_d$, $\widetilde{\phi}_{off}$, and $\widetilde{\phi}_{ex,off}$ represent the average efficiency of the three groups of domestic firms in equilibrium (see Section 2.6.2 in the appendix). To be more concrete, $\widetilde{\phi}_d$ denotes the average efficiency of firms that neither export nor import, $\widetilde{\phi}_{off}$ that of firms only engaged in offshoring, and $\widetilde{\phi}_{ex,off}$ the efficiency of firms that simultaneously import intermediates and export final goods. The mass of firms in each group is M_d, M_{off}, and $M_{ex,off}$. Similarly, M denotes the total mass of domestic firms and M_t the mass of all firms active in country H. By symmetry, $\widetilde{\phi}_t$ is also the average efficiency of all domestic firms, taking into account the foreign sales of domestic exporters and controlling for transport costs τ.

It is now straightforward to express all aggregate variables as functions of the

average efficiency $\widetilde{\phi}_t$:

$$
\begin{aligned}
P_X &= M_t^{\frac{1}{1-\sigma}} p(\widetilde{\phi}_t) \\
R_X &= M_t r_H(\widetilde{\phi}_t) = M r(\widetilde{\phi}),
\end{aligned}
$$

Furthermore, welfare per worker, W, is captured by the real wage rate:

$$
W = \frac{w}{P} = w\hat{\beta}\left[M_t^{\frac{1}{1-\sigma}}p(\widetilde{\phi}_t)\right]^{-\beta} = \widehat{\varphi}_{min}^{\beta}w\hat{\beta}\left[\frac{\rho}{w^{1-\alpha}(p_I^d)^{\alpha}}\right]^{\beta}\left(\frac{\beta L}{\sigma f_p}\right)^{\frac{\beta}{\sigma-1}}. \quad (2.17)
$$

Notice that $P = P_X^{\beta}p_Y^{1-\beta}/\hat{\beta} = P_X^{\beta}/\hat{\beta}$, where $\hat{\beta} = [\beta^{\beta}(1-\beta)^{1-\beta}]$. Domestic labor supply, L, is exogenous. Also, recall that w and p_I^d are determined by labor productivity in the homogeneous goods sectors.

It is important to realize that domestic welfare rises with the minimum productivity, $\widehat{\varphi}_{min}$. Analogous reasoning applies to the other advanced economies. However, welfare in country W is fixed at φ_Y^w, as households in W consume only the numeraire good Y. Since the nominal wage rate in terms of the numeraire is fixed, so is welfare in country W.

2.3.5   Open economy equilibrium

Differentiated good sector

There is market entry in off-equilibrium situations, with new firms competing profits away. Market entry in the differentiated good sector is subject to fixed costs f_e in terms of labor. Failure must be taken into account, as paying the fixed costs of entry does not guarantee that the entrant's productivity draw exceeds $\widehat{\varphi}_{min}$. Therefore, expected profits are given by $\nu_{in}\bar{\pi}$, where $\nu_{in} = 1 - G(\widehat{\varphi}_{min})$ is the ex-ante probability of successful entry and $\bar{\pi} = \pi(\widetilde{\phi})$ is the average profit of all surviving domestic firms in sector X. Firms enter as long as expected profits exceed fixed market entry costs $f_e w$. This yields the free entry (FE) condition:

$$
\bar{\pi} = \frac{f_e w}{\nu_{in}}. \quad (2.18)
$$

Furthermore, average profits of domestic firms earned at home and abroad, $\bar{\pi}$, can be written as:

$$
\bar{\pi} = \nu_d \pi(\widetilde{\phi}_d) + \nu_{off}\pi(\widetilde{\phi}_{off}) + \nu_{ex,off}\pi(\widetilde{\phi}_{ex,off}). \quad (2.19)
$$

Notice that ν_d, ν_{off}, and $\nu_{ex,off}$ stand for the probabilities of belonging to one of the three equilibrium groups of firms, conditional on successful entry: $\nu_d = [G(\widehat{\varphi}_{off}) - G(\widehat{\varphi}_{min})]/[1 - G(\widehat{\varphi}_{min})]$, $\nu_{off} = [G(\widehat{\varphi}_{ex,off}) - G(\widehat{\varphi}_{off})]/[1 - G(\widehat{\varphi}_{min})]$,

and $\nu_{ex,off} = [1 - G(\widehat{\varphi}_{ex,off})]/[1 - G(\widehat{\varphi}_{min})]$. Also, recall that average profits are functions of the minimum productivity level $\widehat{\varphi}_{min}$. Following Melitz (2003), equation (2.19) is called the zero cutoff profit condition (ZCP). The ZCP and FE conditions together identify a unique equilibrium, as illustrated by Figure 2.3 (see Section 2.6.3 in the appendix for details).
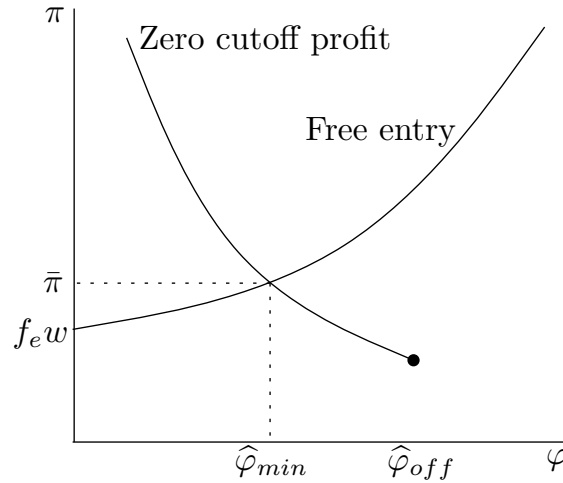
Figure 2.3 Open economy equilibrium. See Section 2.6.3 in the appendix for details.

Market clearing

The world market for good X clears if

$$(n + 1)E_X = (n + 1)\beta wL = (n + 1)R_X. \tag{2.20}$$

Hence aggregate revenues in sector X are exogenously fixed: $R_X = \beta wL$. This implies that, if P_X falls, aggregate output in the differentiated good sector will increase.

For the world market for homogeneous good Y to clear, total demand must equal supply. Due to Cobb-Douglas preferences, consumers will always spend a fraction $(1 - \beta)$ of their total expenditure on good Y. Consumers in country W spend their entire income on the homogeneous final good. Thus:

$$(n + 1)E_Y + E_Y^w = (n + 1)(1 - \beta)wL + w^w L^w = (n + 1)Y + Y^w. \tag{2.21}$$

Since world demand for good Y is fixed, changes in Y and Y^w need to cancel out. Hence an increase in the supply of good Y in the advanced economies, say, must be compensated by a decrease in the supply originating in country W. Then labor market clearing in W requires that labor shifts to sector I: $L^w = L_Y^w + L_I^w$. Consequently, W's output of intermediates will increase.

The domestic labor market is in equilibrium if $L = L_Y + L_I + L_X + L_e$. Here, L_e denotes labor used upon entry in the manufacturing sector: $L_e = M f_e$. M is the mass of firms in equilibrium. This mass is determined by the free-entry condition: $f_e = [1 - G(\widehat{\varphi}_{min})]\bar{\pi}/w$. Combining the preceding equations yields: $L_e = M\bar{\pi}/w$. Hence profits in sector X are fully paid out to the investment workers facilitating entry. This ensures that total household income equals the wage bill.

The world market for intermediate goods is in equilibrium if the advanced economies' demand for intermediates equals the world supply of intermediates. Furthermore, trade between the advanced economies is always balanced, by the symmetry assumption. Finally, recall that country W imports good Y and exports its entire output of intermediates, $p_I^w I^w$. Hence W's trade with the group of advanced economies (expressed in terms of f.o.b. prices) is balanced if $p_I^w I^w = E_Y^w - Y^w$.

2.4   The impact of economic integration

The model presented in the previous section allows me to study the impacts of economic integration on individual firms, international trade, and aggregate welfare in a comparative static analysis. The first step consists of exploring the consequences of lower variable offshoring costs. It is shown that a decline in these costs stimulates trade in differentiated final goods. In a second step, the impacts of changes in other model parameters are briefly discussed. The formal analysis is relegated to Section 2.6.4 in the appendix.

2.4.1   Competition effects of lower marginal offshoring costs

Over the last two decades, the "glue" holding together individual production stages in close geographical proximity has gradually melted (Baldwin 2006). For instance, new forms of telecommunication - such as the internet - have facilitated the monitoring and coordination of remote links of the supply chain. At the same time, political liberalization has reduced artificial barriers to trade in intermediates. In particular, a number of countries - including China and the Central and Eastern European countries - that lend themselves to produce intermediates for the advanced economies have been gradually integrated into the world economy. In the model, these developments are captured by a drop in variable offshoring costs, τ_I. All other exogenous parameters, including the variable costs of exporting final goods, remain unchanged.[3]

---

[3]Note that τ_I and τ not only differ because they are related to different goods (intermediate versus final goods), but also because they apply to different country pairs. Trade costs of final goods, τ, concern trade among the advanced countries, while trade costs τ_I relate to trade

What are the impacts of a marginal drop in variable offshoring costs? The new equilibrium is determined by the zero-cutoff profit condition (ZCP) and the free entry condition (FE). While the FE condition in equation (2.18) remains unaffected by the change in τ_I, the ZCP condition in (2.19) shifts to the right in (φ, π) space. As a result, the cutoff productivity level in the new equilibrium, $\widehat{\varphi}'_{min}$, is higher than the one in the previous equilibrium. (Notice that variables with a prime correspond to the new equilibrium with lower offshoring costs.) With slight abuse of terminology, this finding can be summarized as follows:[4]

Result R.1 *Competition intensifies. A marginal drop in variable offshoring costs (τ_I) forces the least productive firms to quit the domestic market.*

This may come as a surprise, because the least productive firms do not engage in offshoring (due to the fixed offshoring costs) and, therefore, are not directly affected by changes in τ_I. However, they are harmed by an indirect effect stemming from increased competition in the domestic market. Several mechanisms are at play. To start with, all firms that already sourced their intermediates from abroad before the drop in τ_I see their marginal cost fall, because the c.i.f. price of foreign intermediates declines. Moreover, lower offshoring costs render foreign sourcing profitable for more domestic firms, i.e. the cutoff productivity $\widehat{\varphi}_{off}$ falls. The decrease in input costs of incumbent and new offshoring firms translates into lower prices of their varieties. This downward pressure on the aggregate price level P_X stiffens competition in the domestic market. In addition, additional foreign exporters enter the domestic market, intensifying competition further. All these mechanisms contribute to the extinction of the least productive firms.

2.4.2 Trade effects of lower marginal offshoring costs

One can now move on to show that the drop in variable offshoring costs stimulates not only trade in intermediates but also trade in differentiated final goods. More specifically, one can demonstrate that lower offshoring costs allow incumbent exporters to increase their export quantities (intensive margin) and enable additional domestic firms to become exporters (extensive margin).

Turning to the extensive margin first, notice that, for a marginal fall in variable offshoring costs from τ_I to τ'_I, we have:

$$\frac{\widehat{\varphi}'_{ex,off}}{\widehat{\varphi}_{ex,off}} = \left(\frac{\tau'_I}{\tau_I}\right)^{\alpha} \left(\frac{\widehat{\varphi}'_{min}}{\widehat{\varphi}_{min}}\right) < 1. \tag{2.22}$$

---

between the workbench country and the advanced countries.

[4]Of course, the overall degree of competition in the differentiated good sector is indexed by σ. Hence the intensification of competition actually refers to the deterioration in the relative prices of low-productivity firms.

The first term on the right-hand side of the equality captures the direct effect of lower variable offshoring costs on incumbent offshoring firms. A drop in τ_I leads to lower marginal costs and, ceteris paribus, higher profits from foreign sales. This direct effect makes exporting profitable for some firms that were previously unable to sell to foreign markets. However, there is also an indirect effect - captured by the second term on the right-hand side - stemming from the increase in competition. This countervailing effect diminishes the profitability of exporting, because stiffened competition weighs on the market shares of less productive exporters. At first sight, it appears that the overall effect is ambiguous. Yet, one can show analytically that the direct effect will always outweigh the indirect effect so that the overall effect is positive (see Section 2.6.4 in the appendix, equation (2.29)). Thus, lower variable offshoring costs always lead to a decrease in the export cutoff productivity, allowing additional domestic firms to enter the export markets.[5]

A reduction in offshoring costs also boosts exports of differentiated final goods through the intensive margin, i.e. incumbent exporters increase their export quantities. This reflects a cross-country reallocation of market shares from low-productivity to high-productivity firms. More specifically, incumbent exporters from country H experience a drop in input costs, which allows them to sell their variety at a lower price. This, in turn, gives them a competitive edge in foreign markets over local competitors whose productivity is too low to render offshoring profitable. Notably, price competitiveness vis-à-vis competing exporters from third countries does *not* improve. Since the advanced economies are assumed to be perfectly symmetric, foreign exporters experience the same drop in input costs as the domestic exporters. Thus, the mirror image of higher domestic exports are diminishing sales of foreign low-productivity, non-exporting firms.

To derive the effect on the intensive margin analytically, notice that, in nominal terms, the intensive margin corresponds to the revenues from foreign sales. Export revenues must rise in response to lower offshoring costs, since

$$\frac{r'_F(\phi^{off})}{r_F(\phi^{off})} = \left[\left(\frac{\tau'_I}{\tau_I} \right)^{\alpha} \left(\frac{\widehat{\varphi}'_{min}}{\widehat{\varphi}_{min}} \right) \right]^{1-\sigma} > 1. \tag{2.23}$$

Here, inequality (2.22) has been used. A similar expression holds for real exports. The key finding can be summarized as follows:

Result R.2 ***The export-magnification effect of offshoring.** A marginal drop in variable offshoring costs (τ_I) fosters intra-industry trade in differentiated*

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[5]It should be noted that one cannot pin down the overall *mass* of new exporters without restrictions on the shape of the productivity distribution function. For the sake of simplicity, the change in the cutoff export productivity is referred to as the change in the extensive margin of exports.

final goods among the advanced economies through both the intensive and extensive margin of trade.

Note that one cannot pinpoint the magnitude of the contributions of the intensive margin and the extensive margin to the overall change in exports without further assumptions on the productivity distribution $g(\varphi)$. The reason is that the mass of exporters entering the foreign market has to be set against the mass of incumbent exporters ramping up their foreign sales.

The expansion of trade between the advanced economies is non-trivial. In the model, the advanced economies trade only differentiated final goods with each other and the distance costs τ associated with this type of international trade have remained unchanged. Thus, the intensification of trade in differentiated final goods stems entirely from the resource reallocation between heterogeneous firms.

At the same time, the drop in τ_I also boosts trade in intermediates between the advanced economies and the workbench country. For one thing, more domestic firms find it profitable to import foreign intermediates ($\widehat{\varphi}_{off}$ falls); for another thing, the more productive firms in the differentiated goods sector, which increase their foreign sales, demand additional imported intermediates. Both effects contribute to an increase in imports of intermediates by the advanced economies. Since trade must be balanced, higher imports of intermediates require an expansion of Home's output and exports in its comparative advantage sector Y. Labor is reallocated from the domestic intermediate good sector to the homogeneous final good sector Y. The additional output units of Y are traded for intermediates from country W. This effect comes on top of the export-magnification effect of offshoring. In other words:

Result R.3 *Inter-industry trade intensifies.* *A marginal drop in variable offshoring costs (τ_I) also intensifies inter-industry trade between the advanced economies and the workbench country. This implies that trade in intermediates increases in parallel to trade in final goods.*

In a nutshell, the export-magnification effect developed in this chapter provides a novel explanation for the growth in world trade over the last two decades. The gradual decline in offshoring costs over this period triggered a "Darwinian evolution" that gave rise to a reallocation of market shares from low-productivity firms to high-productivity exporters. This process stimulated not only trade in intermediates but also trade in differentiated final goods among the advanced economies.

This basic mechanism remains intact if assumption A.3 is violated, i.e. when offshoring-only requires higher productivity than exporting-only. (It should be stressed again that such a partitioning of firms would not be in line with empirical evidence, as presented by Tomiura (2007).) In this case, a drop in variable offshoring costs τ_I still triggers an intra-industry reallocation of resources towards

the more productive firms, which increase their exports. Interestingly, though, a lower τ_I (and, similarly, a lower f_I) is now associated with an increase in the export cut-off. This is because the least productive exporters are not engaged in offshoring and therefore cannot benefit from lower input costs, while being hurt by the indirect effect of increased competition. However, this is counterbalanced by the increase in exports of the more productive exporters. In addition, inter-industry trade is boosted by increased demand for intermediates. In the following, the focus is again on the case in which assumption A.3 holds.

2.4.3 Impacts on revenues, profits, and aggregate welfare

Lower variable offshoring costs also have repercussions on the revenues and profits of individual firms and aggregate welfare. In brief:

Result R.4 *The intra-industry reallocation raises aggregate welfare. A marginal drop in variable offshoring costs (τ_I) leads to an intra-industry realloca-tion of market share and resources towards the more productive firms. The asso-ciated increase in average firm efficiency raises real wages and, thereby, aggregate welfare.*

To see this, note that all incumbent offshoring firms - i.e. firms with relatively high productivity - see their domestic revenues rise:

$$\frac{r'_H(\phi^{off})}{r_H(\phi^{off})} = \frac{r'_F(\phi^{off})}{r_F(\phi^{off})} > 1. \tag{2.24}$$

At the same time, they benefit from higher export sales. For new exporters this is trivial, for seasoned exporters it follows from equation (2.23). Variable profits increase in tandem, as they are proportional to revenues. Hence, all incumbent offshoring firms unequivocally benefit from lower offshoring costs. By contrast, it is unclear whether the firms switching from domestic to foreign sourcing see their profits rise or fall. On the one hand, their domestic revenues rise. On the other hand, they now have to bear the fixed costs of offshoring. However, each of these new offshoring firms realizes higher profits compared to a hypothetical case in which they refrain from offshoring. Low-productivity firms which continue to purchase domestic intermediates have to digest a fall in revenues and profits. Increased competition squeezes their market share, whereas their input costs re-main unchanged. Therefore, the least productive of these firms have to leave the market.

Overall, the marginal fall in offshoring costs leads to an intra-industry real-location of market share and resources towards the more productive firms. As a result, the average firm efficiency is higher in the new equilibrium. The consumer

price index falls, resulting in higher real wages. Thus, welfare unequivocally rises in all advanced economies. While it is not clear whether the product variety available increases (because the number of additional foreign exporters could be smaller than the number of domestic firms leaving the market), this variety-effect is always dominated by the effect of lower average prices (see equation 2.17). However, the associated adjustments involve a significant reallocation of labor both between and within sectors. Such an adjustment process is likely to be painful in the presence of frictions in labor and goods markets, which have been assumed away.

As already indicated, welfare in the workbench country W is tied to labor productivity in sector Y and therefore not affected by the change in offshoring costs.

2.4.4   Other comparative statics

One might expect that the impacts of a change in *fixed* offshoring costs (f_I) are very similar to those of lower variable offshoring costs. However, a drop in fixed offshoring costs actually raises the minimum productivity cut-off level necessary to become a successful exporter ($\widehat{\varphi}_{ex,off}$) (see Section 2.6.4 in the appendix). Hence some incumbent exporters are forced to stop selling their goods abroad. The reason is that, on the one hand, competition abroad intensifies, as some foreign firms engage in offshoring for the first time and thereby improve their competitiveness. On the other hand, the marginal domestic firm that is indifferent between exporting and staying at home is assumed to be already engaged in offshoring. Hence, a decline in fixed offshoring costs has no impact on the marginal costs of this firm. As a result, exporting becomes unprofitable for the marginal exporter. (By contrast, variable offshoring costs enter the marginal costs and therefore affect foreign sales prospects.) In addition, surviving exporters see their export revenues fall. Hence the drop in f_I also has a negative effect on trade in differentiated final goods at the intensive margin. At the same time, however, there is a positive effect on inter-industry trade. Lower fixed costs of offshoring, f_I, prompt more firms to import foreign intermediates from the workbench country (i.e. $\widehat{\varphi}_{off}$ falls). In return, exports of the homogeneous good Y also rise. Hence the effect of a drop in f_I on total trade is generally ambiguous. Nevertheless, welfare in the advanced economies unequivocally increases.

The results so far have shown that changes in variable offshoring costs have important consequences for the firms' export decision. However, the converse is also true, i.e. changes in parameters related to final goods' trade among the advanced economies also affect the firms' offshoring decision. In fact, both a decrease in the variable cost of trading final goods (τ) and a drop in the corresponding fixed costs (f_{ex}) raise the cutoff productivity for offshoring firms, $\widehat{\varphi}_{off}$ (see Section 2.6.4 in the appendix). The weakest firms that previously engaged in offshoring are hurt by

the deflection of demand toward foreign exporters and have to switch to domestic sourcing. Interestingly, the intensification of competition stems entirely from the entry of new foreign exporters. In contrast, changes in offshoring costs also stiffen competition through a second channel, namely the boost in competitiveness of all domestic firms that are able to offshore. This channel is absent in the case of a reduction in τ, since lower trade costs among the advanced countries do not affect the marginal cost of producing for the home market. It is also worth noting that the results are fully consistent with Melitz (2003). Hence, qualitatively, changes in the parameters related to trade in final goods (τ, f_{ex} and n) have the same consequences on the minimum cutoff productivity and the exporting threshold as in the Melitz model.

2.5   Conclusion

World trade drastically increased in the two decades preceding the global downturn of 2008-09. Based on a general equilibrium model with heterogeneous firms, this chapter argued that the *export-magnification effect of offshoring* helps explain the surge in world trade. The underlying mechanism is simple and intuitive, but non-trivial. To be more concrete, the model suggests that the decline in offshoring costs seen over the past decades has, first, allowed more and more firms in the advanced economies to cut production costs by importing intermediates from low-wage countries and, second, brought down the input costs of incumbent offshoring firms. This improvement in price competitiveness allowed these final goods producers to ramp up their exports (intensive margin) or to become exporters for the first time (extensive margin). As a result, international trade in differentiated final goods among the advanced economies intensified. Crucially, the export-magnification effect reflects a reallocation of market shares towards the high-productivity firms, since only these firms are able to bear the fixed costs associated with offshoring and exporting.

This narrative should be seen as a complement to other explanations of the expansion of world trade over the last two decades, such as the one provided by Yi (2003). That said, the mechanism proposed here has the advantage of being consistent with the stylized fact that the share of intermediates in total trade has remained broadly stable over recent years. In essence, I have shown analytically how trade in intermediates boosts trade in final goods.

There are several promising avenues for future research in this field. First, it would be interesting to build a similar model featuring offshoring between advanced economies. Empirically, similar countries tend to trade intermediates heavily among each other (Grossman and Rossi-Hansberg 2008*a*). Second, the model could be extended to allow for asymmetries across the advanced economies, par-

ticularly as regards the productivity distributions in the differentiated good sector. This would open up the possibility that domestic exporters improve their competitiveness vis-à-vis foreign exporters, too, rather than only vis-à-vis foreign non-offshoring, non-exporting firms.

2.6   Appendix to Chapter 2

2.6.1   Ranking of cutoff productivity levels

The following ranking of productivity cutoff levels has been assumed: $\widehat{\varphi}_{min} < \widehat{\varphi}_{off} < \widehat{\varphi}_{ex,off}$. This appendix demonstrates that assumptions A.1-A.3 indeed ensure that this ranking holds.

To start with, notice that

$$\widehat{\varphi}_{min} < \widehat{\varphi}_{off} \qquad \Leftrightarrow \qquad \frac{p_I^{off}}{p_I^d} > \left(\frac{f_p}{f_I + f_p} \right)^{\frac{1}{\alpha(\sigma-1)}} \equiv \tilde{p}_1$$

$$\widehat{\varphi}_{off} < \widehat{\varphi}_{ex,off} \qquad \Leftrightarrow \qquad \frac{p_I^{off}}{p_I^d} < \left(1 - \frac{f_I}{f_{ex}\tau^{\sigma-1}} \right)^{\frac{1}{\alpha(\sigma-1)}} \equiv \tilde{p}_2.$$

Assumption A.3 ensures that $\tilde{p}_1 < \tilde{p}_2 < 1$. Thus, the ordering $\widehat{\varphi}_{min} < \widehat{\varphi}_{off} < \widehat{\varphi}_{ex,off}$ holds if

$$\tilde{p}_1 < \frac{p_I^{off}}{p_I^d} < \tilde{p}_2 < 1. \tag{2.25}$$

This ranking holds true under assumptions A.1-A.3. In words, if the relative price of intermediates is neither too large nor too small, then the cutoff productivity levels will be ordered as described in the main text.

In principle, firms could also opt for a fourth strategy, i.e. exporting without offshoring. However, under assumptions A.1-A.3, this strategy is always dominated by another strategy. The derivation of this result is relatively straightforward and therefore omitted.

2.6.2   Aggregation

In equilibrium, sector X hosts three kinds of firms. Let M denote the equilibrium mass of incumbent firms in this sector. Then the mass of all domestic firms involved neither in exporting nor in offshoring is given by $M_d = \nu_d M$. Furthermore, the mass of incumbent offshoring firms is $M_{off} = \nu_{off}M$ and the mass of domestic exporters $M_{ex,off} = \nu_{ex,off}M$. Finally, the mass of all firms serving the domestic market, including foreign exporters, is $M_t = M + nM_{ex,off}$.

Let $\widetilde{\phi}_d$ be the average efficiency of all domestic firms that neither export nor engage in offshoring. Analogously, $\widetilde{\phi}_{off}$ stands for the average efficiency of all domestic firms that purchase foreign intermediates without exporting and $\widetilde{\phi}_{ex,off}$ for the average efficiency of all domestic exporters also engaged in offshoring. Then

these averages can be written as:

$$\widetilde{\phi}_d = \left\{ \frac{1}{G(\widehat{\varphi}_{off}) - G(\widehat{\varphi}_{min})} \int_{\widehat{\varphi}_{min}}^{\widehat{\varphi}_{off}} \left[\frac{\varphi}{\left(p_I^d\right)^\alpha} \right]^{\sigma-1} g(\varphi)\,\mathrm{d}\,\varphi \right\}^{\frac{1}{\sigma-1}}$$

$$\widetilde{\phi}_{off} = \left\{ \frac{1}{G(\widehat{\varphi}_{ex,off}) - G(\widehat{\varphi}_{off})} \int_{\widehat{\varphi}_{off}}^{\widehat{\varphi}_{ex,off}} \left[\frac{\varphi}{\left(p_I^{off}\right)^\alpha} \right]^{\sigma-1} g(\varphi)\,\mathrm{d}\,\varphi \right\}^{\frac{1}{\sigma-1}}$$

$$\widetilde{\phi}_{ex,off} = \left\{ \frac{1}{1 - G(\widehat{\varphi}_{ex,off})} \int_{\widehat{\varphi}_{ex,off}}^{\infty} \left[\frac{\varphi}{\left(p_I^{off}\right)^\alpha} \right]^{\sigma-1} g(\varphi)\,\mathrm{d}\,\varphi \right\}^{\frac{1}{\sigma-1}}.$$

Notice that all averages of firm efficiency depend on the productivity cutoff levels. Since these cutoffs are functions of $\widehat{\varphi}_{min}$, the same is true for the averages. In particular:

$$\tilde{\phi}_t = \widehat{\phi}_{min} \left[\frac{r_H(\tilde{\phi}_t)}{r_H(\widehat{\phi}_{min})} \right]^{\frac{1}{\sigma-1}} = \frac{\widehat{\varphi}_{min}}{(p_I^d)^\alpha} \left(\frac{\beta L}{M_t \sigma f_p} \right)^{\frac{1}{\sigma-1}}.$$

2.6.3 Open economy equilibrium

This appendix proves that the zero cutoff profit (ZCP) condition and the free entry (FE) condition together identify a unique cutoff level $\widehat{\varphi}_{min}$, as in Melitz (2003). To start with, recall that the ZCP and FE conditions together imply:

$$f_e w = [G(\widehat{\varphi}_{off}) - G(\widehat{\varphi}_{min})]\pi(\widetilde{\phi}_d) + [G(\widehat{\varphi}_{ex,off}) - G(\widehat{\varphi}_{off})]\pi(\widetilde{\phi}_{off})$$
$$+ [1 - G(\widehat{\varphi}_{ex,off})]\pi(\widetilde{\phi}_{ex,off}). \tag{2.26}$$

Average profits of the three groups of firms occurring in equilibrium are given by:

$$\pi(\widetilde{\phi}_d) = \left[\left(\frac{\widetilde{\phi}_d}{\widehat{\phi}_{min}} \right)^{\sigma-1} - 1 \right] f_p w$$

$$\pi(\widetilde{\phi}_{off}) = \left[\left(\frac{\widetilde{\phi}_{off}}{\widehat{\phi}_{min}} \right)^{\sigma-1} - 1 \right] f_p w + \left[\left(\frac{\widetilde{\phi}_{off}}{\widehat{\phi}_{off}} \right)^{\sigma-1} - 1 \right] f_I w$$

$$\pi(\widetilde{\phi}_{ex,off}) = \left[\left(\frac{\widetilde{\phi}_{ex,off}}{\widehat{\phi}_{min}} \right)^{\sigma-1} - 1 \right] f_p w + \left[\left(\frac{\widetilde{\phi}_{ex,off}}{\widehat{\phi}_{off}} \right)^{\sigma-1} - 1 \right] f_I w$$

$$+ \left[\left(\frac{\widetilde{\phi}_{ex,off}}{\widehat{\phi}_{ex,off}} \right)^{\sigma-1} - 1 \right] n f_{ex} w$$

To condensate equation (2.26), two auxiliary functions are defined:

$$U(\varphi', \varphi'') = \int_{\varphi'}^{\varphi''} \left(\frac{\zeta}{(p_I(\zeta)^\alpha} \right)^{\sigma-1} g(\zeta) \, \mathrm{d}\zeta$$
$$V(\varphi', \varphi'') = G(\varphi'') - G(\varphi').$$

Now, noting that $V(\varphi', \varphi'') + V(\varphi'', \varphi''') = V(\varphi', \varphi''')$ and $U(\varphi', \varphi'') + U(\varphi'', \varphi''') = U(\varphi', \varphi''')$, equation (2.26) can be recast as follows:

$$\begin{aligned} f_e = & \left[(\widehat{\phi}_{min})^{\sigma-1} U(\widehat{\varphi}_{min}, \infty) - V(\widehat{\varphi}_{min}, \infty) \right] f_p \\ & + \left[(\widehat{\phi}_{off})^{1-\sigma} U(\widehat{\varphi}_{off}, \infty) - V(\widehat{\varphi}_{off}, \infty) \right] f_I \\ & + \left[(\widehat{\phi}_{ex,off})^{1-\sigma} U(\widehat{\varphi}_{ex,off}, \infty) - V(\widehat{\varphi}_{ex,off}, \infty) \right] n f_{ex}. \end{aligned} \tag{2.27}$$

To boil down the preceding equation even further, one can define:

$$\begin{aligned} j(\varphi) &= \phi(\varphi)^{1-\sigma} U(\varphi, \infty) - V(\varphi, \infty) \\ &= [1 - G(\varphi)] \left[\left(\frac{\widetilde{\phi}(\varphi)}{\phi(\varphi)} \right)^{\sigma-1} - 1 \right] = [1 - G(\varphi)] k(\varphi). \end{aligned}$$

Here,

$$\widetilde{\phi}(\varphi)^{\sigma-1} = \frac{1}{1 - G(\varphi)} \int_{\varphi}^{\infty} \left(\frac{\zeta}{(p_I(\zeta)^\alpha} \right)^{\sigma-1} g(\zeta) \, \mathrm{d}\zeta$$
$$k(\varphi) = \phi(\varphi)^{1-\sigma} \widetilde{\phi}(\varphi)^{\sigma-1} - 1.$$

Equation (2.27) can then be rewritten as follows:

$$f_p j(\widehat{\varphi}_{min}) + f_I j(\widehat{\varphi}_{off}) + n f_{ex} j(\widehat{\varphi}_{ex,off}) = f_e. \tag{2.28}$$

Recall that $\widehat{\varphi}_{off}$ and $\widehat{\varphi}_{ex,off}$ are implicitly defined as functions of $\widehat{\varphi}_{min}$ by equations (2.12) and (2.14).

It is now straightforward to show that equation (2.28) identifies a unique cutoff level $\widehat{\varphi}_{min}$ and that the ZCP curve cuts the FE curve from above in (φ, π) space. In fact, the proof is analogous to Melitz (2003) and therefore omitted. One should keep in mind, however, that the ZCP curve has a discontinuity at $\varphi = \widehat{\varphi}_{off}$. At this point, $\phi(\varphi)$ switches from $\varphi/(p_I^d)^\alpha$ to $\varphi/(p_I^{off})^\alpha$. That said, the previous assumptions ensure that the equilibrium $\widehat{\varphi}_{min}$, i.e. the intersection of the ZCP and FE curves, is strictly to the left of this discontinuity, in the range $(0, \widehat{\varphi}_{off})$. In this subset, $j(\varphi)$ and therefore the ZCP curve are continuous.

Having identified $\widehat{\varphi}_{min}$, equations (2.12) and (2.14) determine the remaining cutoff levels $\widehat{\varphi}_{off}$ and $\widehat{\varphi}_{ex,off}$. All other endogenous variables can be expressed as functions of these three cutoff levels.

2.6.4   Comparative statics

In this appendix, the comparative statics described in Section 2.4 are derived analytically.

Lower τ_I

Differentiating equation (2.28) with respect to τ_I yields:

$$\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,\tau_I} = -\frac{\alpha\widehat{\varphi}_{min}}{\tau_I\hat{p}}\frac{f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + nf_{ex}j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}\hat{p}}{f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min} + nf_{ex}j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}} < 0$$

Here, $\hat{p} \equiv 1 - (p_I^{off}/p_I^d)^{\alpha(\sigma-1)} < 1$.

Since $\mathrm{d}\,\widehat{\varphi}_{min}/\mathrm{d}\,\tau_I > -\alpha\widehat{\varphi}_{min}/(\tau_I\hat{p})$, we have:

$$\frac{\mathrm{d}\,\widehat{\varphi}_{off}}{\mathrm{d}\,\tau_I} = \frac{\alpha\widehat{\varphi}_{off}}{\tau_I\hat{p}} + \frac{\widehat{\varphi}_{off}}{\widehat{\varphi}_{min}}\frac{\partial\widehat{\varphi}_{min}}{\partial\tau_I} > 0.$$

Hence the direct effect of a decrease in τ_I on $\widehat{\varphi}_{off}$ dominates the indirect effect operating through $\widehat{\varphi}_{min}$. Similarly, since $\mathrm{d}\,\widehat{\varphi}_{min}/\mathrm{d}\,\tau_I > -\alpha\widehat{\varphi}_{min}/\tau_I$:

$$\frac{\partial\widehat{\varphi}_{ex,off}}{\partial\tau_I} = \frac{\alpha\widehat{\varphi}_{ex,off}}{\tau_I} + \frac{\widehat{\varphi}_{ex,off}}{\widehat{\varphi}_{min}}\frac{\partial\widehat{\varphi}_{min}}{\partial\tau_I} > 0. \tag{2.29}$$

To verify this, notice that $\mathrm{d}\,\widehat{\varphi}_{min}/\mathrm{d}\,\tau_I > -\alpha\widehat{\varphi}_{min}/\tau_I$ can be rewritten as follows:

$$\hat{p}^{-1} - 1 < \frac{f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min}}{f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off}}$$

$$< \frac{f_p}{f_I}\frac{\int_{\widehat{\varphi}_{min}}^{\infty}\left(\frac{\zeta}{p_I(\zeta)^\alpha}\right)^{\sigma-1}g(\zeta)\,\mathrm{d}\zeta}{\int_{\widehat{\varphi}_{off}}^{\infty}\left(\frac{\zeta}{p_I(\zeta)^\alpha}\right)^{\sigma-1}g(\zeta)\,\mathrm{d}\zeta}\left(\frac{\phi(\widehat{\varphi}_{off})}{\phi(\widehat{\varphi}_{min})}\right)^{\sigma-1}.$$

Using equation (2.12) and the definition of $\hat{p}$ above, one arrives at:

$$\frac{p_I^{off}}{p_I^d} < \left[\frac{\int_{\widehat{\varphi}_{min}}^{\infty}\left(\frac{\zeta}{p_I(\zeta)^\alpha}\right)^{\sigma-1}g(\zeta)\,\mathrm{d}\zeta}{\int_{\widehat{\varphi}_{off}}^{\infty}\left(\frac{\zeta}{p_I(\zeta)^\alpha}\right)^{\sigma-1}g(\zeta)\,\mathrm{d}\zeta}\right]^{\frac{1}{\alpha(\sigma-1)}}.$$

Under assumption A.1, this condition always holds, since the right-hand side is greater than one.

Lower f_I

$$\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_I} = \frac{\widehat{\varphi}_{min}[1 - G(\widehat{\varphi}_{off})]}{f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min} + f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + nf_{ex}j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}} < 0$$

Since $\mathrm{d}\,\widehat{\varphi}_{min}/\mathrm{d}\,f_I > -\widehat{\varphi}_{min}/[(\sigma-1)f_I]$:

$$\frac{\mathrm{d}\,\widehat{\varphi}_{off}}{\mathrm{d}\,f_I} = \frac{\widehat{\varphi}_{off}}{(\sigma-1)f_I} + \frac{\widehat{\varphi}_{off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_I} > 0$$

$$\frac{\mathrm{d}\,\widehat{\varphi}_{ex,off}}{\mathrm{d}\,f_I} = \frac{\widehat{\varphi}_{ex,off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_I} < 0$$

Lower τ

$$\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,\tau} = -\frac{\widehat{\varphi}_{min}}{\tau}\frac{n f_{ex} j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}}{f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min} + f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + n f_{ex} j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}} < 0$$

$$\frac{\mathrm{d}\,\widehat{\varphi}_{off}}{\mathrm{d}\,\tau} = \frac{\widehat{\varphi}_{off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,\tau} < 0$$

Since $\mathrm{d}\,\widehat{\varphi}_{min}/\mathrm{d}\,\tau > -\widehat{\varphi}_{min}/\tau$:

$$\frac{\mathrm{d}\,\widehat{\varphi}_{ex,off}}{\mathrm{d}\,\tau} = \frac{\widehat{\varphi}_{ex,off}}{\tau} + \frac{\widehat{\varphi}_{ex,off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,\tau} > 0$$

Lower f_{ex}

$$\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_{ex}} = \frac{\widehat{\varphi}_{min} n\left[1 - G(\widehat{\varphi}_{ex,off})\right]}{f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min} + f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + n f_{ex} j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}} < 0$$

$$\frac{\mathrm{d}\,\widehat{\varphi}_{off}}{\mathrm{d}\,f_{ex}} = \frac{\widehat{\varphi}_{off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_{ex}} < 0$$

Since $\mathrm{d}\,\widehat{\varphi}_{min}/\mathrm{d}\,f_{ex} > -\widehat{\varphi}_{min}/[(\sigma-1)f_{ex}]$:

$$\frac{\mathrm{d}\,\widehat{\varphi}_{ex,off}}{\mathrm{d}\,f_{ex}} = \frac{\widehat{\varphi}_{ex,off}}{(\sigma-1)f_{ex}} + \frac{\widehat{\varphi}_{ex,off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,f_{ex}} > 0$$

Higher n

$$\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,n} = -\frac{f_{ex} j(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{min}}{f_p j'(\widehat{\varphi}_{min})\widehat{\varphi}_{min} + f_I j'(\widehat{\varphi}_{off})\widehat{\varphi}_{off} + n f_{ex} j'(\widehat{\varphi}_{ex,off})\widehat{\varphi}_{ex,off}} > 0$$

$$\frac{\mathrm{d}\,\widehat{\varphi}_{off}}{\mathrm{d}\,n} = \frac{\widehat{\varphi}_{off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,n} > 0$$

$$\frac{\mathrm{d}\,\widehat{\varphi}_{ex,off}}{\mathrm{d}\,n} = \frac{\widehat{\varphi}_{ex,off}}{\widehat{\varphi}_{min}}\frac{\mathrm{d}\,\widehat{\varphi}_{min}}{\mathrm{d}\,n} > 0$$

Chapter 3

Vertical linkages and short-term trade dynamics

3.1 Introduction

The short-run sensitivity of trade flows to business cycle fluctuations has increased significantly over the past decades. This became evident during the "Great Trade Collapse" (Baldwin 2009) of 2008-09. The decline in world trade at the time was not only the most severe downturn in post-war history, but also significantly exceeded that in global production. What is more, the increased responsiveness of trade to changes in production and income is not confined to this downturn. Table 3.1 presents estimation results from a simple error correction model in the spirit of Pain, Mourougane, Sédillot and Le Fouler (2005). The model explains the quarterly growth in real OECD imports of goods and services (IM) by the short-run dynamics in domestic demand (DD) and relative import prices ($RIMP$) as well as the deviation from the estimated long-run ("equilibrium") relationship between these variables:[1]

$$
\begin{aligned}
\Delta IM_t = {} & \alpha + \beta_1 \Delta DD_t + \beta_2 \Delta RIMP_t + \beta_3 \Delta IM_{t-1} + \beta_4 \Delta IM_{t-4} \\
& + \gamma \left(IM_{t-1} - DD_{t-1} - \delta_1 RIMP_{t-1} - \delta_2 TREND_t \right) + \epsilon_t.
\end{aligned}
\tag{3.1}
$$

Estimating the model over two distinct sub-samples, it turns out that the short-run coefficient corresponding to domestic demand, β_1, increased significantly over time, from 1.51 in 1970-1989 to 2.66 in 1990-2011 (this holds true if the crisis period is excluded). In other words, a given change in domestic demand nowadays triggers

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[1]In line with the literature, the long-run demand elasticity is set to unity. This implies that the long-run ratio of imports to domestic demand is determined by relative prices. The fact that imports have increased faster than domestic demand over the past decades is picked up by the linear trend in the cointegration relationship.

a more pronounced change in trade flows, as already shown by Irwin (2002) and Freund (2009).

	1970-1989	1990-2011	1970-2011
Constant (α)	-0.15***	-0.07*	-0.06***
Dynamics			
Domestic demand (β_1)	1.51***	2.66***	2.20***
Relative import prices (β_2)	0.24***	0.50***	0.31***
Imports(-1) (β_3)	0.29***	0.16**	0.25***
Imports(-4) (β_4)	-0.10	-0.13**	-0.16***
Error correction (γ)	-0.16***	-0.06**	-0.06***
Long run			
Relative import prices (δ_1)	-0.35***	-0.54	-0.68***
Linear trend (δ_2)	0.00***	0.01***	0.01***
R^2	0.61	0.83	0.70
Durbin-Watson statistic	2.29	2.21	2.31

Table 3.1 Responsiveness of OECD imports to changes in domestic demand. OLS estimates from an error correction model explaining quarterly growth in OECD real imports of goods and services (see main text). Relative import prices are defined as the import deflator divided by the domestic demand deflator. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively. All data are provided by the OECD.

It is widely held that the international fragmentation of production has been a key driver of the increased responsiveness of trade (e.g. Bems, Johnson and Yi 2009, Freund 2009, Irwin 2002, Levchenko, Lewis and Tesar 2010, Tanaka 2009). The idea is that this process has created a finely woven web of cross-country linkages through which shocks can be rapidly transmitted across the globe. However, a rigorous theoretical foundation for the link between the prevalence of vertical linkages and the sensitivity of trade to macroeconomic shocks has been missing so far. This chapter aims to close this gap. Based on a minimal International Real Business Cycle (IRBC) model with vertical linkages, this chapter shows theoretically that closer vertical linkages between countries raise the short-run volatility of international trade, also relative to GDP. Trade flows are also found to become more synchronized across countries as vertical fragmentation gains in importance. These findings complement earlier work by Kose and Yi (2006) which shows that vertical linkages foster cross-country output synchronization.

The analysis in this chapter is based on a two-country RBC model with vertical linkages in the vein of Kose and Yi (2001, 2006). In the model, there are two symmetric countries, each of them hosting three sectors. In the first sector, domestic labor and capital are combined to produce a homogeneous intermediate good. In the second sector, a representative firm bundles domestic and foreign interme-

diates into a non-tradable consumption good. The use of foreign intermediates in domestic production gives rise to vertical linkages across countries. Crucially, trade in intermediates is subject to quadratic transport costs. Transport services are provided by the third sector.

To study the impacts of closer vertical linkages on trade dynamics, this chapter looks at the impulse responses and the simulated second moments of imports and exports under two different scenarios. The scenarios differ only in the level of transport costs associated with international trade in intermediates. Lower transport costs are associated with closer vertical linkages in steady state. The numerical experiments demonstrate that extensive vertical linkages amplify the trade response to idiosyncratic demand and supply shocks. As a result, world trade becomes more volatile, also relative to GDP. Moreover, the cross-country synchronization of trade flows increases as vertical linkages become more important. In a nutshell, the model predicts that in a world with closer vertical linkages trade should become more sensitive to business cycle fluctuations and more synchronized across countries.

Hence the findings of this chapter help explain the exceptional severity and cross-country synchronization of the Great Trade Collapse of 2008-09. The decline in world trade at the time - around 15 percent from peak to trough - was not only unprecedented in post-war history (see Table 3.2), but also significantly exceeded that in global production. While it is well known that trade is among the most volatile GDP components (e.g. Ravn and Mazzenga 2004), empirical trade models nevertheless have difficulties explaining the magnitude of the precipitous contraction in trade in the winter of 2008-09, leaving an unexplained residual of around 30-40 percent (Levchenko et al. 2010, Yi, Bems and Johnson 2010). The theoretical results of this chapter suggest that vertical linkages - which have drastically gained importance over recent years - helped amplify the drop in trade. Of course, this does not exclude that other factors also played an important role in 2008-09, including demand composition effects (Eaton, Kortum, Neiman and Romalis 2011), inventory dynamics (Alessandria, Kaboski and Midrigan 2010), and supply-side financial constraints (Amiti and Weinstein 2009, Chor and Manova 2010, Iacovone and Zavacka 2009). The predictions of the model are also consistent with the fact that the contraction in trade flows in 2008-09 was highly synchronized across countries. In fact, in the final quarter of 2008, all OECD countries reported negative quarterly import growth, most of them at rates in excess of -10 percent. Never before had OECD countries' trade flows reached such a high level of synchronization. A similar picture emerges for major non-OECD economies.

This chapter is also related to a growing literature on the role of vertical linkages in business cycle synchronization. Methodologically, the chapter builds on Kose and Yi (2001, 2006) who study the potential of vertical linkages to resolve

| Episode | Peak | Trough | Quarters to | | Percentage change |
			...trough	...pre-crisis level	trough-to-peak
1969	1968Q4	1969Q1	1	2	-0.3
1971	1971Q3	1971Q4	1	2	-1.3
1974-75	1974Q3	1975Q2	3	6	-7.3
1980	1980Q1	1980Q3	2	4	-2.9
1982	1981Q4	1982Q4	4	6	-3.1
1986	1985Q4	1986Q1	1	2	-0.2
1998	1998Q1	1998Q2	1	2	-0.0
2001	2000Q4	2001Q4	4	6	-3.3
2008-09	2008Q2	2009Q1	3	9	-14.6

Table 3.2 Downturns in world trade (1968-2010). Episodes lasting at least two quarters are marked in bold. The table is based on quarterly seasonally-adjusted data in 2005 US dollars. Sources: OECD (MEI) and own calculations.

the so-called trade co-movement problem.[2] In the more recent paper, Kose and Yi augment the Backus-Kehoe-Kydland (BKK) model with transport costs and generalize it to the three-country case to test whether the augmented model can explain the positive link in the data between bilateral trade intensity and GDP correlation. They demonstrate numerically that country pairs with lower bilateral transport costs and higher trade intensity indeed show higher business cycle co-movement, although the model still fails to replicate the empirical relationship quantitatively. While the macroeconomic literature on vertical linkages has so far been centered on the implications for output co-movement, some papers have studied a variety of other topics ranging from output volatility (Bergin et al. 2007) to the effectiveness of monetary policy (Huang and Liu 2001). This chapter adds to the existing literature in that it focuses on the implications of vertical linkages on the volatility and co-movement of international trade flows.

The remainder of the chapter is structured as follows. Section 3.2 introduces the theoretical model, while Section 3.3 discusses the main results from the quantitative experiments. Section 3.4 concludes.

3.2   The model

The main goal of this chapter is to study the implications of vertical linkages on trade dynamics. For this purpose, I set up a minimal IRBC model with vertical linkages in the vein of Kose and Yi (2001, 2006).

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[2]On this issue, see also Ambler, Cardia and Zimmermann (2002), Arkolakis and Ramanarayanan (2008), Burstein, Kurz and Tesar (2008).

3.2.1 The representative agent

The world consists of two perfectly symmetric countries, Home and Foreign. The world population is normalized to unity. Each country is populated by an infinitely-lived representative agent who acts at time t so as to maximize

$$\mathbb{E}_t \sum_{j=0}^{\infty} \frac{\beta^j \left[c_{t+j}^{\mu}(1 - n_{t+j})^{1-\mu} \right]^{1-\gamma}}{1 - \gamma} \qquad (0 < \mu < 1; 0 < \beta < 1; \gamma > 0). \qquad (3.2)$$

Here, c_t denotes consumption in period t and n_t hours worked. The share of consumption in intratemporal utility is μ, while γ denotes the intertemporal elasticity of substitution and β the discount factor. The fixed time endowment is normalized to 1. All variables are in per capita terms, unless otherwise noted.

The representative agent purchases domestic goods for consumption (c_t) and investment purposes (x_t). Income is derived from labor supply, n_t, and the capital stock carried over from the last period, k_t. The wage and rental rates are given by w_t and r_t. Government consumption, g_t, is financed by lump-sum taxes. All this adds up to the representative agent's period budget constraint:

$$q_t \left(c_t + g_t + x_t \right) = r_t k_t + w_t n_t + \pi_t. \qquad (3.3)$$

Here, q_t denotes the price of the domestic final good (the numeraire) and π_t dividend income. Notice that no financial assets are traded internationally. (The assumption of financial autarky will be relaxed later on.) Kose and Yi (2001) show that, under financial autarky, the relationship between trade intensity and business cycle correlation has the correct sign. With fully integrated asset markets, by contrast, higher trade intensity is actually associated with lower business cycle synchronization. For this reason, I focus on the case of financial autarky in the baseline version of the model.

The capital stock evolves according to the standard law of motion

$$k_{t+1} = (1 - \delta)k_t + x_t \qquad (0 < \delta \leq 1), \qquad (3.4)$$

where δ is the rate of depreciation.

Agents maximize lifetime utility subject to a sequence of budget constraints, as given in (3.3), and capital's law of motion, (3.4). The corresponding first-order conditions are entirely standard:

$$U_1(c_t, 1 - n_t) = \lambda_t q_t \qquad (3.5)$$

$$U_2(c_t, 1 - n_t) = \lambda_t w_t \qquad (3.6)$$

$$\mathbb{E}_t \beta \lambda_{t+1} \left[r_{t+1} + (1 - \delta) q_{t+1} \right] = \lambda_t q_t \qquad (3.7)$$

$$q_t \left[c_t + g_t + k_{t+1} - (1 - \delta)k_t \right] = r_t k_t + w_t n_t + \pi_t. \qquad (3.8)$$

Here, $U_1(c_t, 1 - n_t)$ and $U_2(c_t, 1 - n_t)$ are the partial derivatives of the utility function and λ_t is the Lagrange multiplier. One can combine and rewrite the first three of the preceding equations as follows:

$$\frac{1 - n_t}{c_t} = \frac{(1 - \mu)q_t}{\mu w_t} \tag{3.9}$$

$$\mathbb{E}_t \frac{\beta U_1(c_{t+1}, 1 - n_{t+1})}{U_1(c_t, 1 - n_t)} \left(\frac{r_{t+1}}{q_{t+1}} + 1 - \delta \right) = 1. \tag{3.10}$$

The first equation describes the representative agent's optimal labor-leisure decision, while the second one is a standard Euler equation.

3.2.2 Firms

Each country hosts three sectors. In the first sector, labor and capital are combined to produce an intermediate good. The second sector assembles the final consumption and investment good, using domestic and foreign intermediates as inputs. The use of foreign intermediates in domestic production gives rise to vertical cross-country linkages. The third sector transports intermediates to final goods producers, also across borders.

The intermediate good sector

In the first sector, perfectly competitive firms combine labor and capital to produce an intermediate good. Each economy is completely specialized in the production of a single intermediate good, subject to a Cobb-Douglas production function. Output of intermediates, y_t, is given by:

$$y_t = z_t k_t^\theta n_t^{1-\theta} \qquad (0 < \theta < 1). \tag{3.11}$$

Here, z_t is total factor productivity (TFP), which obeys a stochastic process detailed below. θ represents the share of capital in sectoral value added.

In each period, the representative firm maximizes profits subject to the production technology given in (3.11). The first-order conditions are given by

$$r_t k_t = \theta p_t y_t \tag{3.12}$$

$$w_t n_t = (1 - \theta)p_t y_t, \tag{3.13}$$

where p_t denotes the factory gate price of the intermediate good produced in the home country. Hence relative factor demand is given by:

$$\frac{k_t}{n_t} = \frac{\theta w_t}{(1 - \theta)r_t}. \tag{3.14}$$

The transport sector

The transport sector distributes domestic intermediate goods to domestic and foreign final goods producers. More specifically, the shipping firm buys domestic goods at factory gate prices and sells them at c.i.f. prices. Transport costs within a country are zero. However, international trade in intermediates is subject to transport costs. They include not only shipping costs in a narrow sense but also costs related to artificial trade barriers (such as tariffs) and other distance costs (such as administration and information costs). Following Backus, Kehoe and Kydland (1992), Kose and Yi (2006), Ravn and Mazzenga (1999), transport costs are quadratic in export quantities. This specification takes into account that, at any point in time, it is more costly to transport larger quantities at once. Put differently, the transport technology is associated with decreasing returns to scale. To fix ideas, think of a fixed short-term capacity of vessels (a factor of production which is not explicitly modeled here), which complicates the transport of larger quantities of intermediates. Technically, quadratic transport costs are useful, because - unlike linear costs à la Samuelson - they survive the linearization of the model.

If Home ships $y_{x,t}$ units of intermediates to Foreign, τy_x^2 units will dissipate in transit so that only

$$(1 - \tau y_{x,t}) y_{x,t} \equiv m_t^* \qquad (\tau \geq 0) \tag{3.15}$$

units arrive abroad. Hence m_t^* denotes foreign imports. Notice that $\tau y_{x,t}$ represents the fraction of output lost in transit. In the subsequent numerical experiments, transport costs are expressed as a percentage of steady-state export levels, similar to the approach chosen by Backus et al. (1992). For instance, transport costs of 10 percent are tantamount to $\tau = 0.1/y_{x,0}$, where $y_{x,0}$ is the steady-state level of exports.

Profit maximization, subject to the transport technology (3.15), requires that marginal costs equal marginal revenue:

$$p_t = p_{m,t}^* \left(1 - 2\tau y_{x,t}\right). \tag{3.16}$$

Alternatively, the preceding equation can be interpreted as a no-arbitrage condition stating that, at the margin, the transport firm should be indifferent between selling a unit of the domestic intermediate at home or abroad. Note that $p_{m,t}^*$ is the c.i.f. price of domestic exports, i.e. the price paid by foreign firms for domestic intermediates. The transport firm has positive profits in equilibrium, since $p_t < p_{m,t}^*(1 - \tau y_{x,t})$.[3] These profits are distributed to the owners, i.e. the households,

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[3]Marginal revenue is decreasing in exports: $p_m^*(1 - 2\tau y_{x,t})$. Hence the transport firm earns positive profits on infra-marginal units shipped overseas. Profits would be zero if the transport technology were linear - rather than quadratic - in exports.

and are represented by π_t in equation (3.3).

The final good sector

In the final good sector, the representative firm bundles domestic and foreign intermediates into a final good. Production technology is characterized by a CES function:

$$v_t = \left[\omega m_t^{1-\alpha} + (1-\omega)y_{d,t}^{1-\alpha}\right]^{1/(1-\alpha)} \qquad (0 \le \omega \le 1; \alpha \ge 0). \tag{3.17}$$

Hence v_t is the output of the domestic final good and $y_{d,t}$ denotes the quantity of domestic intermediates used in domestic production. The elasticity of substitution is $1/\alpha$.

The final good producers act under perfect competition and maximize profits, subject to the production technology given in (3.17). The two first-order conditions are:

$$\frac{p_{m,t}}{q_t} = \omega \left[\frac{v_t}{m_t}\right]^{\alpha} \tag{3.18}$$

$$\frac{p_t}{q_t} = (1-\omega) \left[\frac{v_t}{y_{d,t}}\right]^{\alpha}. \tag{3.19}$$

Here, m_t are domestic imports of intermediates, defined analogously to (3.15).

3.2.3   Market clearing and forcing processes

Clearing of the intermediate goods markets requires:

$$y_{d,t} + y_{x,t} = y_t. \tag{3.20}$$

Recall that final goods are not traded in the benchmark version of the model. (This assumption will be relaxed later on.) Hence the market clearing condition for final goods is:

$$v_t = c_t + x_t + g_t. \tag{3.21}$$

Finally, the forcing processes governing total factor productivity and government expenditure are given by:

$$\log \begin{pmatrix} z_t \\ z_t^* \end{pmatrix} = \log \begin{pmatrix} \bar{z} \\ \bar{z}^* \end{pmatrix} + \begin{pmatrix} a_{11} & a_{12} \\ a_{12} & a_{11} \end{pmatrix} \log \begin{pmatrix} z_{t-1} \\ z_{t-1}^* \end{pmatrix} + \begin{pmatrix} \epsilon_{z,t} \\ \epsilon_{z,t}^* \end{pmatrix} \tag{3.22}$$

$$\log \begin{pmatrix} g_t \\ g_t^* \end{pmatrix} = \log \begin{pmatrix} \bar{g} \\ \bar{g}^* \end{pmatrix} + \begin{pmatrix} b_{11} & b_{12} \\ b_{12} & b_{11} \end{pmatrix} \log \begin{pmatrix} g_{t-1} \\ g_{t-1}^* \end{pmatrix} + \begin{pmatrix} \epsilon_{g,t} \\ \epsilon_{g,t}^* \end{pmatrix}. \tag{3.23}$$

The innovations in (3.22) and (3.23) are both distributed normally and independently over time with contemporaneous covariance matrices Σ_z and Σ_g, respectively.

3.2.4 Equilibrium

An equilibrium is a sequence of goods and factor prices and quantities such that the first-order conditions to the firms' and households' maximization problems, as well as the market clearing conditions, are satisfied in every period.

3.2.5 Accounting

For later use, let real imports and real GDP be defined as follows:

$$Imports_t \equiv p_{m,0} m_t \tag{3.24}$$

$$GDP_t \equiv q_0 \left(c_t + x_t + g_t \right). \tag{3.25}$$

Both variables are measured at the prices of a base period, namely the steady state, and are expressed in per capita terms. Notice that gross nominal output is given by $py + qv + p_m^* m^*$, where the third element refers to revenue in the domestic transport sector. Subtracting intermediate consumption, i.e. $py_d + p_m m + py_x = py + p_m m$, gives nominal GDP: $qv + p_m^* m^* - p_m m$. Using the final goods market clearing condition and imposing balanced trade, one arrives at equation (3.25). Finally, notice that the terms of trade are given by either p_m/p_m^* (in c.i.f. terms) or p^*/p (in f.o.b. terms).

3.2.6 Calibration and solution

Since the model has no closed-form solution, it is linearized around a symmetric steady state. To make the results comparable with related work, the calibration closely follows Backus, Kehoe and Kydland (1994) and Kose and Yi (2001). A quarterly frequency is chosen.

The two countries are symmetric, also in terms of country size. The quarterly rate of depreciation, δ, is set to 0.025. The discount factor β equals 0.989, so that the quarterly rate of return on capital (net of depreciation) is roughly 1 percent. The share of consumption in the utility function, μ, is set to 0.34 and the coefficient of relative risk aversion, γ, is 2. In steady state, consumption accounts for 65 percent of final good absorption, government expenditure for 10 percent and investment for the remaining 25 percent. The shares are in line with long-run averages for the United States, as reported in the Penn World Table.[4] The capital-output ratio is 10.

Following Backus et al. (1994) and Kose and Yi (2001), the elasticity of substitution between domestic and foreign goods in the Armington aggregator, $1/\alpha$, is set to 1.5. The capital share in production, θ, equals 0.36. In line with Kose and

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[4]See Heston, Summers and Aten (2009).

Yi (2001), the Armington weights (i.e. the ω's) are chosen such that the steady-state import shares under free trade equal those actually observed in U.S. data. A standard value for the import shares in the IRBC literature is 0.15 (e.g. Backus et al. 1994, Heathcote and Perri 2004). The implied Armington weight is $\omega = 0.24$. As regards the trade cost parameter τ, several alternative values corresponding to transport costs ranging from zero to 30 percent of steady-state exports are considered. This makes it possible to study the role of higher trade in intermediates on macroeconomic dynamics.

The specification of the shock processes closely follows Ravn and Mazzenga (2004) who, in turn, draw on Backus et al. (1992). More specifically, the symmetric matrices **A** and **B** associated with, respectively, the technology and government expenditure shocks are specified as:

$$\mathbf{A} = \begin{bmatrix} 0.906 & 0.0883 \\ 0.0883 & 0.906 \end{bmatrix}, \qquad \mathbf{B} = \begin{bmatrix} 0.95 & 0 \\ 0 & 0.95 \end{bmatrix}. \tag{3.26}$$

The standard deviation of the productivity innovations in both countries is 0.00852, while the cross-country correlation between these innovations is 0.258. As regards the government expenditure shocks, there are no cross-country spillovers. The first-order autocorrelation is 0.95, while the standard deviation of the innovations is 0.02 in both countries. Table 3.3 summarizes the baseline calibration.

Parameter	Baseline calibration
Preferences	
μ	0.34
γ	2
β	0.989
Technology	
θ	0.36
δ	0.025
α	1/1.5
ω	0.24

Table 3.3 Summary of baseline calibration

3.3   How vertical linkages affect trade dynamics

How do vertical linkages affect the dynamics of aggregate trade flows? To find an answer to this question, the model presented in Section 3.2 is solved and simulated

under different levels of transport costs.[5] In essence, this numerical experiment replicates the longer-term decline in distance costs observed over the past decades. New forms of telecommunication, in particular, have facilitated the coordination and monitoring of distant production activities. At the same time, political liberalization has provided a powerful catalyst. As a result, the "glue" (Baldwin 2006) that once held together individual production stages in close geographical proximity gradually melted away, giving rise to extensive vertical linkages.

3.3.1 Impulse response analysis

To gain some intuition for the model mechanics, it is useful to study the impulse responses of key variables to transitory shocks under different levels of transport costs. This prepares the ground for a full-fledged simulation in Section 3.3.2.

As a benchmark, consider the case in which trade in intermediates is subject to transport costs of 30 percent. To fix ideas, think of this "high transport costs" case as the situation prevailing two decades ago, before the vertical fragmentation of production gained momentum. How does the economy react in such a setting to a temporary drop in total factor productivity (TFP) in the domestic intermediate goods sector by one standard deviation?[6] The impulse responses of key variables are shown in Figure 3.1 in the appendix. Not surprisingly, output in the intermediate good sector declines immediately. Moreover, domestic firms cut back on their inputs of labor and, with a lag, capital, thereby further aggravating the decline in domestic output of intermediates. Lower productivity also translates into an increase in the factory-gate price of domestic intermediates. In fact, there is an improvement in the domestic terms of trade, defined as the c.i.f. price of domestic imports divided by the c.i.f. price of domestic exports (p_m/p_m^*). Domestic final goods producers take advantage of this change in relative input prices by partially substituting foreign intermediates for domestic ones. Their output of final goods also declines, sending the domestic economy into recession. Since there is no intertemporal trade in the baseline version of the model, private consumption declines together with current income.

The domestic recession is transmitted to the foreign country through the trade channel. More specifically, the terms-of-trade effect makes foreign factors of production effectively less productive and thereby acts to synchronize the countries' business cycles, as already noted by Kose and Yi (2006). As a consequence, the factor demand of foreign firms declines together with GDP, although the recession

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[5]The following analysis makes use of Dynare, a free software package designed for the analysis of DSGE models. It is available online: http://www.dynare.org.

[6]For the time being, the off-diagonal elements of matrix **A** are set to zero. Abstracting from contemporaneous technology spillovers allows to focus on the role of vertical linkages in the transmission of shocks.

is less severe than in Home.[7] The drop in foreign final demand, together with the change in the relative prices of intermediates, reduces world demand for Home's intermediate good. In fact, the decline in foreign imports is steeper than that in domestic imports, due to the terms-of-trade effect. To see this, notice that balanced trade requires $p_m m = p_m^* m^*$. Home's terms-of-trade improvement therefore implies that the contraction in the quantity of foreign imports has to exceed the drop in the quantity of domestic imports. The retrenchment in foreign imports (and exports) is also more severe than that in foreign GDP, i.e. the trade intensity declines.

Now, suppose transport costs decline on the back of technological progress and political liberalization. This gives rise to tighter vertical linkages in steady state. More specifically, the steady-state share of imported intermediates in GDP - i.e. $Imports_0/GDP_0$ - rises from 10 percent to 15 percent as transport costs fall from 30 to 0 percent, all other things being the same.

How does the economy now respond to the same asymmetric TFP shock examined above? For the sake of simplicity, consider the extreme case of zero transport costs. (The main findings also apply to smaller reductions in transport costs, as shown in the following figures and tables.) The most important finding is that the collapse of international trade is steeper in both countries under free trade compared with the benchmark (see Figure 3.1 in the appendix). The amplification effect is quantitatively important. Extensive vertical linkages also aggravate the recession in the foreign country. Meanwhile, the impulse response of domestic GDP remains almost unchanged compared with the benchmark. Thus, the cross-country GDP co-movement increases, as already demonstrated by Kose and Yi (2006). Crucially, Home's terms-of-trade improvement is more pronounced if intermediates are traded freely. More specifically, the drop in the prices of both domestic and foreign intermediates is smaller than in the benchmark case.

To understand the mechanisms driving the main results, it is useful to have a closer look at the terms-of-trade effect. The first part of the intuition, which draws on Kose and Yi (2006), explains why the terms of trade adjust more forcefully as transport costs fall. The second part clarifies why a sharper adjustment in the relative price of intermediates is associated with a more severe contraction in international trade.

To start with, think of world demand for Home's intermediate good as being the sum of domestic and foreign demand. As it turns out, the foreign demand component is more sensitive to changes in prices than the domestic component. In other words, Foreign's demand curve for the domestic intermediate is flatter than

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[7]The fact that the GDPs co-move - in line with the data - reflects the assumption of financial autarky, which shuts off the resource-shifting mechanism responsible for BKK's "quantity anomaly". Heathcote and Perri (2004) show that an RBC model with financial autarky generally has a better fit than a complete markets model.

Home's own demand curve for the same product. (By the same token, Home's demand curve for the foreign intermediate is flatter than Foreign's demand curve.) To see this, notice that the overall effect of a change in the price of the domestic intermediate consists of a substitution and an income effect. On the one hand, an increase in the price of the domestic intermediate prompts final goods producers in both countries to partially substitute foreign intermediates for domestic ones. On the other hand, the change in the terms of trade also affects income. In Home, the positive income effect partially offsets the drop in demand for domestic intermediates, whereas the negative income effect in Foreign reinforces the substitution effect. As a result, the reduction in the quantity of domestic intermediates demanded is more severe in Foreign, i.e. Foreign's demand curve is flatter.

As transport costs fall, foreign firms increase their steady-state absorption of domestic intermediates. Hence Foreign receives a larger weight in world demand for Home's intermediate good, leading to a flatter world demand curve. This change in the composition of world demand dampens the terms-of-trade effect in response to an asymmetric TFP shock in Home. However, there is a second mechanism working in the opposite direction. As transport costs fall, the steady-state share of imported inputs in Home's production also increases, thereby magnifying the effect of a change in the terms of trade on domestic income. This makes Home's demand curve, and thereby the world demand curve, steeper. Under the baseline calibration, the second mechanism dominates. In brief, lower transport costs are associated with a steeper world demand curve for the domestic intermediate, which amplifies the terms-of-trade adjustment in response to an asymmetric TFP shock.

To complete the intuition, recall that an improvement in the domestic terms of trade renders foreign factors effectively less productive. Since Home's terms-of-trade improvement is more pronounced under free trade, the sharper decline in Foreign's marginal value product gives rise to a steeper fall in foreign production. Weaker economic activity, in turn, is associated with lower imports from Home. At the same time, foreign exports experience a steeper downturn, since the price of foreign intermediates declines less than in the "high transport costs" case. Therefore, the contraction in international trade is more severe under free trade in intermediates.

As it turns out, lower transport costs also amplify the trade response to a demand shock. To be more concrete, consider a temporary decline in domestic government expenditure by one standard deviation. Figure 3.2 shows that an expansion in vertical linkages is associated with a steeper contraction in trade. Lower transport costs also amplify the negative repercussions on foreign GDP.

3.3.2   Simulation

The results of the impulse response analysis suggest that trade becomes more volatile as transport costs fall. To verify this hypothesis, the model is simulated over 120 quarters under different levels of transport costs (1,000 times for each level of transport costs). Notice that both countries are now directly exposed to shocks.[8]

The full-fledged simulation confirms that trade becomes more volatile in a world with more extensive fragmentation of production. In both countries, the volatility of imports and exports increases as transport costs decline (see Table 3.4). This is accompanied by a notable increase in the variability of the terms of trade when they are expressed in c.i.f. terms. What is more, the standard deviation of trade also increases relative to that of GDP, despite the fact that production also becomes more volatile.

This finding is consistent with empirical evidence showing that international trade has become more sensitive to changes in production and income over the past two decades (see Section 3.1). The model results suggest that this phenomenon has been partially driven by the increasing vertical fragmentation of production. The preceding findings also put a new complexion on the Great Trade Collapse of 2008-09, when the drop in international trade significantly exceeded that in GDP, both at the global level and in a number of major economies (including the United States). As already indicated, empirical trade models had a hard time explaining the magnitude of the trade collapse, leaving an unexplained residual of around 30-40 percent (Levchenko et al. 2010, Yi et al. 2010). The findings of this chapter suggest that vertical linkages were an important factor behind this surprisingly steep drop in trade. Put differently, the Great Trade Collapse can be seen as a manifestation of a longer-term development, in which the increased importance of vertical linkages raises the responsiveness of international trade to macroeconomic shocks.

The model also predicts that a decline in transport costs amplifies the cross-country synchronization of international trade flows. In fact, the correlation between domestic and foreign imports increases by a factor of 2.5 as transport costs fall from 30 to 0 percent (see Table 3.6). This is not entirely trivial, since the assumption of balanced trade puts a constraint on trade values at market prices rather than trade quantities. Hence the model provides an intuitive theoretical explanation for the synchronized nature of the trade collapse of 2008-09.

At the same time, the cross-country correlation of output also increases with lower transport costs, as already demonstrated by Kose and Yi (2001, 2006). Looking at this finding from a cross-sectional angle, the business cycle synchronization

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[8]Also, contemporaneous technology spillovers are now taken into account, i.e. the off-diagonal elements of **A** are those given in (3.26).

of a country pair can be expected to increase not only with the overall level of bilateral trade (Clark and van Wincoop 2001, Frankel and Rose 1998) but also with the intensity of bilateral vertical linkages. This is indeed consistent with recent cross-country evidence by Ng (2010) who finds that bilateral production fragmentation has a positive impact on bilateral GDP correlations. It is also in line with di Giovanni and Levchenko (2010) who find that the amplification effect of trade linkages on sectoral output correlation is stronger for industries with high vertical production linkages.

Unfortunately, the model clearly fails to replicate the ranking of the standard deviations of trade and GDP typically observed in the data. Empirically, the standard deviation of imports and exports tends to be significantly higher than that of output. For instance, looking at quarterly data from a cross-section of 14 OECD economies over the period 1970-2000, Ravn and Mazzenga (2004) find that the standard deviation of trade exceeds that of output by a factor of 2-3. Similarly, the volatility of the terms of trade is approximately two times that of output. (By contrast, the standard deviation of net exports, as a percentage of GDP, is only 0.7 times that of output.) In the model, trade flows are clearly less volatile than GDP. The same is true for the terms of trade, at least in the baseline scenario. However, this is a well-known shortcoming of standard IRBC models, including the Backus et al. (1994) model.[9] While the presence of transport costs breaks the tight link between the terms of trade and the marginal rate of transformation between domestic and foreign products established by a frictionless model, as described by Ravn and Mazzenga (2004), this is not enough to bring the volatility of trade and the terms of trade in line with their empirical counterparts.

Intuitively, raising the steady-state import share should at least bring the volatility of international trade flows closer to that of GDP. This is indeed the case. However, the relative standard deviation of trade remains implausibly small even when the import share is lifted rather strongly from the baseline level of 0.15 to 0.5 (see Table 3.4). Nevertheless, it is reassuring that the main findings still go through. In particular, lower transport costs are associated with higher trade volatility and closer cross-country synchronization of trade flows and GDP.

Other basic sensitivity checks confirm that the main findings are robust to variation in key model parameters. In particular, the increase in the volatility of trade remains intact when the elasticity of substitution between domestic and foreign goods $(1/\alpha)$ is lowered from 1.5 to 0.9 (see Table 3.4). Interestingly, however, the cross-country correlation of trade falls slightly in this case as transport costs fall. Furthermore, shutting off the mechanical transmission of shocks through contem-

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[9]Ravn and Mazzenga (2004), for instance, note that "the high variability of trade is one of the aspects that international trade models cannot easily account for". The low variability of the terms of trade, in turn, is part of the well-known "price puzzle".

poraneous technology spill-overs, as was done in Section 3.3.1, does not affect the main results (see Table 3.4).

In a nutshell, the model predicts that an expansion of vertical linkages increases the volatility of trade relative to GDP and the cross-country co-movement of trade flows. The main findings are robust to basic sensitivity checks. The following section presents two slightly more ambitious modifications of the model to further robustify the main findings of this chapter.

3.3.3   Model modifications

Back-and-forth trade

So far, the model allowed only intermediates to be traded internationally. To check whether this restrictive assumption on the composition of international trade is driving the results, trade in final goods is now incorporated. For the sake of simplicity, trade in final goods is assumed to be frictionless. This extension of the model effectively introduces back-and-forth trade. Final goods producers make use of imported intermediates and then partially export their products to foreign markets.

Final goods trade is motivated by household preferences. More specifically, households now consume both domestic and foreign goods according to a Cobb-Douglas function:

$$c_t = c_{F,t}^\nu c_{H,t}^{1-\nu} \qquad (0 < \nu < 1). \tag{3.27}$$

Here, $c_{H,t}$ $(c_{F,t})$ is the consumption of goods from country H (F) by the domestic representative agent and ν denotes the expenditure share of foreign goods. Optimal intratemporal allocation of consumption requires:

$$c_{H,t} = c_t \left(\frac{1-\nu}{\nu} \frac{q_{F,t}}{q_{H,t}} \right)^\nu \tag{3.28}$$

$$c_{F,t} = c_t \left(\frac{\nu}{1-\nu} \frac{q_{H,t}}{q_{F,t}} \right)^{1-\nu}. \tag{3.29}$$

Similar expressions hold for investment and government consumption. The corresponding expenditure shares of foreign goods are denoted by ν_x and ν_g. The overall price index of domestic composite consumption is given by:

$$q_t = \nu^{-\nu}(1-\nu)^{-(1-\nu)} q_{F,t}^\nu q_{H,t}^{1-\nu}. \tag{3.30}$$

Again, similar expressions hold for the price indices corresponding to the investment and government consumption bundles, respectively. The domestic consumption bundle, c_t, remains the numeraire ($q = 1$). Notice that, in equations (3.18)

and (3.19), q_t is now replaced by $q_{H,t}$. In equation (3.7), q is replaced by q_x, where q_x is the price index corresponding to the composite investment bundle. Furthermore, the period budget constraint is now given by:

$$q_t c_t + q_{g,t} g_t + q_{x,t} x_t = r_t k_t + w_t n_t + \pi_t. \tag{3.31}$$

For notational convenience, let $a_{H,t} \equiv c_{H,t} + x_{H,t} + g_{H,t}$ and $a_{F,t} \equiv c_{F,t} + x_{F,t} + g_{F,t}$ denote, respectively, domestic and foreign absorption of the domestic final good. Then the market clearing condition for the domestic consumption and investment good can be written as:

$$a_{H,t} + a_{H,t}^* = v_t. \tag{3.32}$$

Real total imports (i.e. imports of intermediate and final goods) and real GDP are now given as:

$$Imports_t \equiv p_{m,0} m_t + q_{F,0} a_{F,t} \tag{3.33}$$
$$GDP_t \equiv q_{H,0} a_{H,t} + q_{F,0} a_{F,t}. \tag{3.34}$$

In the subsequent numerical experiments, the Cobb-Douglas parameter is assumed to be the same for private and government consumption as well as investment: $\nu = \nu_g = \nu_x = 0.06$. This implies that the steady-state share of foreign goods in total domestic expenditure is 6 percent, broadly in line with aggregate U.S. data. Furthermore, the steady-state share of intermediate inputs is now 9 percent, which corresponds to $\omega = 0.18$. Hence total imports, i.e. imports of intermediate and final goods, make up 15 percent of GDP, as in the benchmark case.

Replicating the preceding numerical experiments with the augmented model, it turns out that the presence of final goods trade does not compromise the main insights gathered so far. In fact, the standard deviation of total trade, including both intermediate and final goods, is virtually the same as in the baseline scenario and rises with lower transport costs (see Table 3.5). Moreover, the cross-country co-movement of total imports increases again as the economy moves towards free trade, albeit less dramatically than in the baseline scenario (see Table 3.6). Additional numerical experiments (not reported here) show that the main results also go through for other reasonable combinations of ν, ν_g, and ν_x when the overall steady-state import share is held constant at 0.15.

Financial integration

As a final robustness check, this section relaxes the assumption of financial autarky. Apart from this modification, the model is identical to the baseline case.

Households are now allowed to trade a real bond, which is expressed in terms of Home's intermediate good. The new budget constraint can be written as

$$q_t \left(c_t + g_t + x_t\right) + p_t \left(\frac{b_{t+1}}{1 + i_t} + \frac{1}{2}\phi b_{t+1}^2\right) = r_t k_t + w_t n_t + p_t b_t + \pi_t, \qquad (3.35)$$

where b_{t+1} denotes the bonds carried over from period t to $t+1$ and i_t is the return on the real bond. There are quadratic bond holding costs in the vein of Kollmann (2004) to ensure the stationarity of the model: $0.5\phi b_{t+1}^2$ (with $\phi > 0$). However, to minimize their impact on model dynamics, a value close to zero is assigned to the parameter ϕ.

As regards the household's optimization problem, the additional first-order condition with respect to bond holdings b_{t+1} can be written as:

$$\mathbb{E}_t \beta \lambda_{t+1} p_{t+1} = \lambda_t p_t \left(\frac{1}{1 + i_t} + \phi b_{t+1}\right). \qquad (3.36)$$

Assuming that international bond holdings are zero in steady state ($b_0 = 0$), we have $i_0 = (1 - \beta)/\beta = r_0/q_0 - \delta$.

The market clearing condition for the domestic intermediate good is now given by:

$$y_{d,t} + y_{x,t} + \frac{1}{2}\phi b_{t+1}^2 + \frac{1}{2}\phi \left(b_{t+1}^*\right)^2 = y_t. \qquad (3.37)$$

Finally, bond market clearing requires that the bond be in zero net supply:

$$b_t + b_t^* = 0. \qquad (3.38)$$

Turning to the results, the standard deviation of trade is virtually unchanged compared with the baseline scenario and rises with trade liberalization (see Table 3.5). The same applies to the relative standard deviation, although GDP is slightly more volatile than in the baseline and its correlation with trade flows has significantly increased. Since the presence of financial linkages activates the well-known resource-shifting mechanism, the cross-county GDP correlation becomes negative as transport costs approach zero. The de-synchronization of the two economies is also reflected in imports, whose cross-country correlation declines as transport costs fall.

To summarize, the main findings of this chapter are robust to several reasonable modifications. In particular, the positive link between vertical linkages and the volatility of trade survives if international trade in final goods or financial assets is allowed. The result that vertical linkages go hand in hand with increased trade synchronization remains unaffected if final goods are traded across borders, but breaks down in the presence of an internationally traded real bond.

3.4 Conclusion

Imports and exports have always tended to fluctuate more vigorously over the business cycle than GDP (Ravn and Mazzenga 2004). Over the past two decades, however, this empirical regularity has become even more pronounced. In fact, empirical evidence shows that international trade has become more sensitive to macroeconomic shocks. A case in point is the collapse of world trade in the winter of 2008-09, which was more severe than a standard empirical trade model would have predicted on the basis of the actual decline in economic activity (Levchenko et al. 2010, Yi et al. 2010). It is widely held that the increasing importance of vertical cross-country linkages has been a key driver of the increase in the responsiveness of trade to macroeconomic shocks.

This chapter is a first attempt to provide a rigorous theoretical foundation for this narrative. The analysis is based on a minimal IRBC model with vertical linkages in the vein of Kose and Yi (2001, 2006). Numerical experiments within this framework demonstrate that closer vertical linkages between countries, brought about by lower transport costs, raise the volatility of international trade. In addition, international trade becomes more synchronized across countries (under certain conditions). The main results are quite robust to several modifications of the model. Hence the model establishes a causal link between the build-up of extensive vertical linkages across the globe over the past two decades and the simultaneous increase in the sensitivity of trade to macroeconomic shocks. Moreover, the results suggest that the severity of the Great Trade Collapse of 2008-09 partly reflected the increased responsiveness of trade on the back of pervasive vertical linkages.

3.5   Appendix to Chapter 3
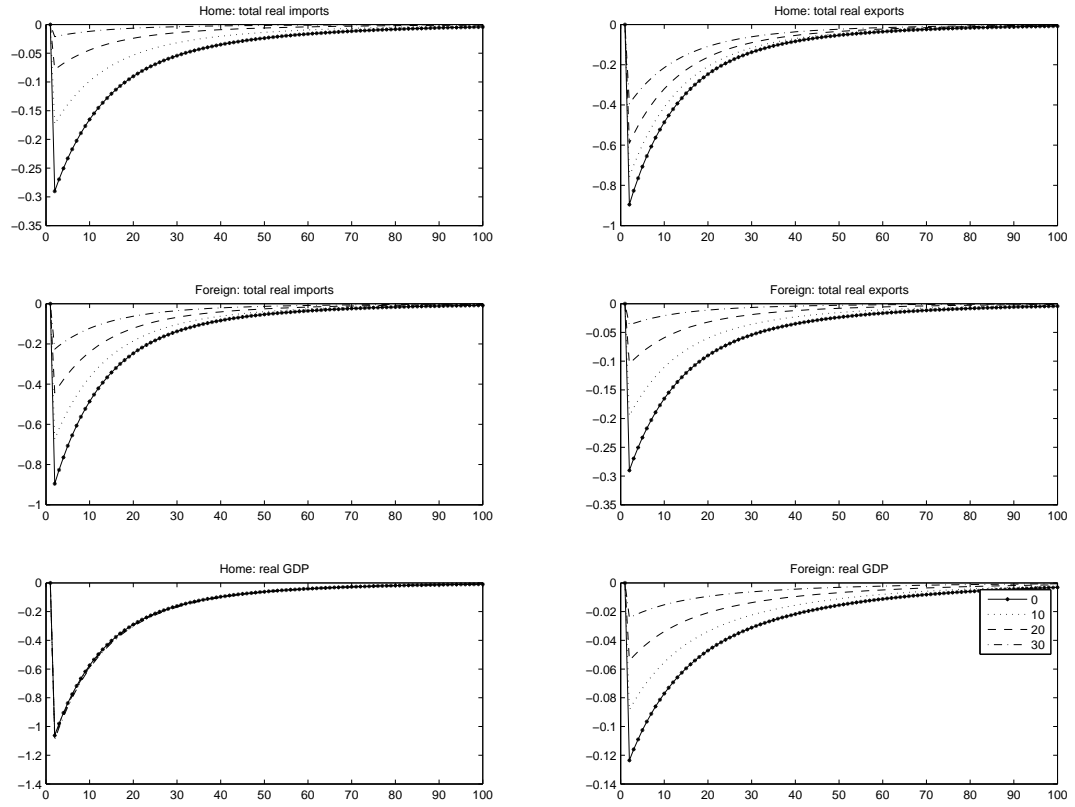
Figure 3.1 Impulse responses to an adverse productivity shock in the home country (with $a_{12} = b_{12} = 0$).
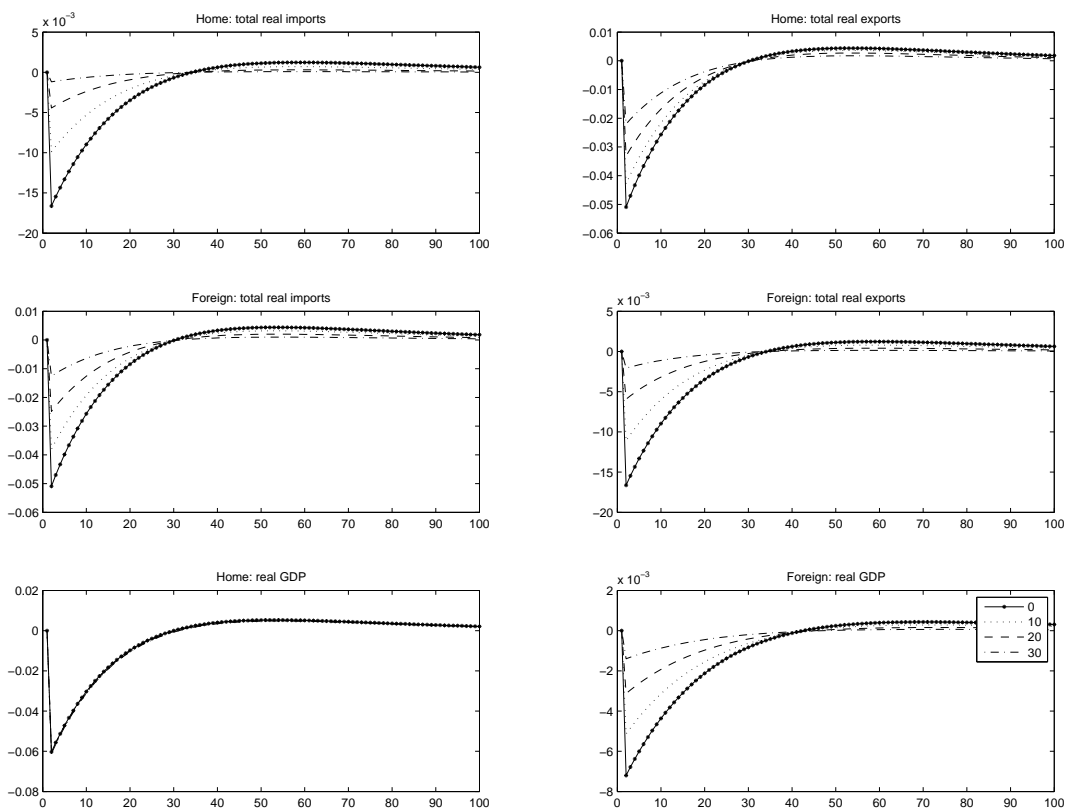
Figure 3.2 Impulse responses to an adverse government expenditure shock in the home country (with $a_{12} = b_{12} = 0$).

	percentage standard deviation 1 - transport costs				relative standard deviation (a) 1 - transport costs				correlation with GDP 1 - transport costs			
	0.7	0.8	0.9	1.0	0.7	0.8	0.9	1.0	0.7	0.8	0.9	1.0
baseline scenario												
imports	0.01	0.04	0.06	0.10	0.02	0.05	0.09	0.13	0.18	0.28	0.38	0.47
GDP	0.69	0.70	0.71	0.72	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
terms of trade (c.i.f.)	0.31	0.55	0.75	0.90	0.45	0.79	1.07	1.27	0.66	0.64	0.62	0.59
terms of trade (f.o.b.)	1.11	1.03	0.96	0.90	1.63	1.49	1.37	1.27	0.66	0.64	0.62	0.59
higher import share (0.5)												
imports	0.04	0.10	0.18	0.26	0.12	0.26	0.42	0.54	0.30	0.49	0.66	0.77
GDP	0.36	0.39	0.44	0.49	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
terms of trade (c.i.f.)	0.32	0.57	0.77	0.92	0.90	1.47	1.80	1.91	0.58	0.46	0.34	0.24
terms of trade (f.o.b.)	1.17	1.08	0.99	0.92	3.27	2.77	2.30	1.91	0.58	0.46	0.34	0.24
lower elasticity (0.9)												
imports	0.04	0.07	0.11	0.13	0.06	0.11	0.15	0.19	0.14	0.20	0.26	0.31
GDP	0.67	0.69	0.70	0.72	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
terms of trade (c.i.f.)	0.53	1.01	1.47	1.86	0.81	1.48	2.11	2.63	0.62	0.56	0.51	0.46
terms of trade (f.o.b.)	1.94	1.91	1.88	1.86	2.92	2.80	2.71	2.63	0.58	0.56	0.51	0.46
no technology spill-overs												
imports	0.01	0.03	0.06	0.09	0.02	0.05	0.09	0.13	-0.08	0.03	0.15	0.25
GDP	0.70	0.71	0.71	0.72	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
terms of trade (c.i.f.)	0.36	0.63	0.87	1.05	0.51	0.90	1.23	1.48	0.75	0.74	0.71	0.69
terms of trade (f.o.b.)	1.29	1.19	1.11	1.05	1.85	1.70	1.58	1.48	0.75	0.74	0.71	0.69

Table 3.4 Simulated second moments, averaged over 1,000 simulations à 120 quarters. Underlying data are HP-filtered (smoothing parameter 1,600). For details see main text. Note that exports and imports are equally volatile. The theoretical second moments are identical in both countries due to symmetry. (a) Relative to real GDP.

	percentage standard deviation				relative standard deviation [a]				correlation with GDP			
	1 - transport costs				1 - transport costs				1 - transport costs			
	0.7	0.8	0.9	1.0	0.7	0.8	0.9	1.0	0.7	0.8	0.9	1.0
baseline scenario												
imports	0.01	0.04	0.06	0.10	0.02	0.05	0.09	0.13	0.18	0.28	0.38	0.47
GDP	0.69	0.70	0.71	0.72	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
terms of trade (c.i.f.)	0.31	0.55	0.75	0.90	0.45	0.79	1.07	1.27	0.66	0.64	0.62	0.59
terms of trade (f.o.b.)	1.11	1.03	0.96	0.90	1.63	1.49	1.37	1.27	0.66	0.64	0.62	0.59
with trade in final goods												
total imports	0.04	0.05	0.07	0.09	0.07	0.08	0.11	0.14	0.33	0.36	0.40	0.45
GDP	0.61	0.62	0.63	0.63	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
terms of trade (c.i.f.)	0.11	0.47	0.80	1.05	0.18	0.77	1.29	1.67	0.62	0.61	0.60	0.58
terms of trade (f.o.b.)	1.36	1.24	1.13	1.05	2.24	2.03	1.83	1.67	0.62	0.61	0.60	0.58
(incomplete) financial integration												
imports	0.01	0.03	0.07	0.11	0.02	0.05	0.08	0.13	0.86	0.88	0.89	0.91
GDP	0.71	0.75	0.80	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
terms of trade (c.i.f.)	0.80	0.70	0.58	0.47	1.14	0.94	0.73	0.54	0.67	0.70	0.69	0.51
terms of trade (f.o.b.)	0.46	0.46	0.46	0.47	0.66	0.62	0.58	0.54	0.55	0.55	0.54	0.51

Table 3.5 Simulated second moments, averaged over 1,000 simulations à 120 quarters. Underlying data are HP-filtered (smoothing parameter 1,600). For details see main text. Note that exports and imports are equally volatile. The theoretical second moments are identical in both countries due to symmetry. (a) Relative to GDP.

	cross-country correlation			
	1 - transport costs			
	0.7	0.8	0.9	1.0
baseline scenario				
imports	0.25	0.40	0.53	0.63
GDP	0.11	0.16	0.23	0.29
higher import share (0.5)				
imports	0.28	0.42	0.54	0.61
GDP	0.32	0.57	0.77	0.89
lower elasticity (0.9)				
imports	0.05	0.04	0.03	0.02
GDP	0.23	0.36	0.48	0.57
no technology spill-overs				
imports	-0.01	0.16	0.32	0.44
GDP	-0.15	-0.09	-0.03	0.04
with trade in final goods				
total imports	0.44	0.47	0.52	0.58
GDP	0.21	0.24	0.27	0.31
(incomplete) financial integration				
imports	0.50	0.46	0.35	0.16
GDP	0.05	0.02	-0.04	-0.13

Table 3.6 Simulated cross-country correlations, averaged over 1,000 simulations à 120 quarters. Underlying data are HP-filtered (smoothing parameter 1,600). For details see main text. Note that exports and imports are equally volatile. The theoretical second moments are identical in both countries due to symmetry.

Chapter 4

A DSGE model with truly endogenous vertical linkages

4.1 Introduction

Offshoring takes place along two dimensions. The *extensive* margin of offshoring refers to the range of production activities located offshore. The *intensive* margin relates to the quantity of a given intermediate imported from abroad. This terminology follows Kohler (2004*b*). In the field of international trade theory, models devoted to the determinants of offshoring typically allow firms to decide on both the intensive and extensive margins of offshoring. The model developed in Chapter 2 is in this tradition. By contrast, standard DSGE models (but also many Computable General Equilibrium models) build on Armington aggregators to capture vertical linkages. In the vein of Armington (1969), intermediates are differentiated by country of origin. This means that firms only decide on the imported quantities of foreign intermediates (intensive margin), while the extensive margin of offshoring is treated as exogenously given. The model presented in Chapter 3 also made use of this modeling strategy.

Armington aggregators clearly have their merits, particularly on the grounds of modeling parsimony. However, the notion of geographically differentiated intermediates becomes increasingly questionable in a world where distance costs are rapidly falling and many intermediate inputs are provided electronically. Moreover, it is unclear how the shutdown of the extensive margin of offshoring in typical DSGE models affects the international transmission of shocks. On the one hand, one would not expect firms to switch back and forth between domestic and foreign sourcing of a particular intermediate over the business cycle in a significant way. Contractual obligations, information costs and similar frictions are likely to render such a footloose sourcing strategy unprofitable. On the other hand, there need

not be large fluctuations in the extensive margin (i.e. actual movement) for it to play a role in macroeconomic dynamics. The mere potential for firms to relocate production stages (i.e. mobility) might be enough to make a difference.[1]

Against this backdrop, I construct a medium-scale Dynamic Stochastic General Equilibrium (DSGE) model where both the intensive and extensive margins of offshoring are endogenous. The model combines a standard DSGE framework with a production module in the spirit of Dornbusch et al. (1977).[2] This theoretical framework allows me to test numerically if endogenizing the extensive margin affects the economy's dynamic responses to macroeconomic shocks. The natural benchmark is the same model in which the extensive margin is exogenously fixed.

In the baseline model, production of final goods requires a continuum of intermediate products. The technology underlying the production of intermediates is linear in labor. Final goods producers can source their intermediates either domestically or from abroad and they can vary the imported quantity of each intermediate. Hence both margins of offshoring are endogenous. Endogenizing the extensive margin means that a new first-order optimality condition is added to the model, which links the international division of labor to relative factor prices. I propose two alternative scenarios differing in how the extensive margin is pinned down. In the first scenario, firms can take advantage of cross-country wage differentials. However, offshoring is subject to per-unit distance costs, which vary by intermediate, as in Grossman and Rossi-Hansberg (2008b). The idea is that some production stages are more easily located far away from the headquarters or the place of final assembly. Firms relocate all tasks for which the lower wage bill outweighs the variable costs of offshoring. Hence only intermediates with relatively low offshoring costs are being offshored. The drawback of this modeling strategy is that, with only one factor of production involved in the production of intermediates, offshoring must be a one-way phenomenon. The reason is that only firms from the high-wage country will ever find it optimal to incur offshoring costs to relocate tasks to the foreign country. Moreover, if the countries are symmetric in steady state, offshoring can only occur as a temporary response to transitory wage differentials in the face of macroeconomic shocks. This is arguably a poor

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[1]In a paper devoted to the endogenous tradability of final goods, Bergin and Glick (2006) argue along similar lines. They show that a macro model in which the margin between traded and non-traded goods is endogenous does a better job in explaining the low volatility of the relative price between traded and non-traded goods compared to real exchange rates. Bergin and Glick give the following interpretation of their results: "It should be noted that the results of this paper in no way rely upon implausibly large numbers of firms switching between traded and non-traded status, but rather upon the simple fact that firms have the ability to make such a switch." (p.3)

[2]Dornbusch et al. (1977) study international specialization and trade in a one-factor, two-country Ricardian model with a continuum of goods. For other applications of the Dornbusch-Fischer-Samuelson approach in macroeconomics, see, for instance, Bergin and Glick (2005, 2006).

representation of the real-world offshoring patterns. For this reason, the second scenario explores a different offshoring motive. Here, not the offshoring costs differ across tasks, but the production technology does, varying across tasks and countries. Put differently, the labor requirements for some intermediates are lower in Home, whereas foreign workers are more adept in producing the remaining intermediates. This model variant is consistent with symmetry in steady state (apart from the fact that each country offshores another part of the task continuum, which is meaningless in this context). The intermediates produced offshore are those for which production costs are lower abroad. In equilibrium, both countries will be engaged in offshoring.

The chapter is related to a few papers studying the impacts of offshoring on macroeconomic dynamics. Bergin et al. (2007) construct (two variants of) a DSGE model to explain why the volatility of economic activity in Mexican offshoring industries (maquiladoras) is roughly twice as high as that in their U.S. counterparts. In the model, a variable cost activity can be relocated from the United States to Mexico, while fixed-cost R&D activities are tied to the United States. In one variant of the model, international differences in production technologies and wages determine endogenously which industries are involved in offshoring, as in Feenstra and Hanson (1995). Bergin et al. (2007) assume ad hoc that only variable-cost activities can be offshored, while fixed-cost activities are tied to the home country. In this chapter, by contrast, individual tasks do not differ in their inherent volatility. Bergin et al. (2007) primarily aim at replicating stylized facts on the industry level, while the focus of this chapter is at the macroeconomic level. Moreover, Bergin et al. (2007) model offshoring as an industry-specific phenomenon, while I regard it primarily as a task-specific or input-specific phenomenon. The extensive margin of offshoring runs along tasks, not final goods industries. Herein, I follow Grossman and Rossi-Hansberg (2008b).[3]

Another closely related paper is the two-country, two-factor dynamic Ricardian model by Yi (2003), which allows for endogenous relocation of production stages. Final goods are produced in three sequential stages. The first two stages yield intermediate goods, which are then costlessly assembled into final goods. (The purpose of the second stage is, essentially, to amplify the effects of a tariff cut by allowing for multiple border crossings of intermediate goods.) Yi assumes that the first two stages can be located in both countries and determines the pattern of international specialization endogenously in the vein of Dornbusch et al. (1977). Yi's focus is on two puzzles linked to the longer-term growth in international trade which can be partly resolved by allowing for multiple border crossings of intermediate goods. Consequently, the model lacks the frictions and shocks that

---

[3]For an illuminating juxtaposition of industry-specific and input-specific offshoring paradigms see Kohler (2008).

are by now standard in DSGE models. Also, his concept of offshoring (or vertical specialization, in Yi's terminology) requires that a final good produced with foreign intermediate inputs be partly exported to other countries.

The remainder of this chapter is structured as follows. In Section 4.2, I construct a DSGE model in which both the intensive and the extensive margins of offshoring are endogenous. Section 4.3 studies the dynamics of this model, while Section 4.4 concludes.

4.2   The model

4.2.1   Firms

There are two countries, Home and Foreign. In the following, I will concentrate on the domestic economy. Unless noted otherwise, the basic structure of the economy is the same abroad. Foreign variables are denoted by asterisks.

Home produces a continuum of final goods varieties $z \in [0, n]$. All varieties are traded in a monopolistically competitive world market and all firms are perfectly symmetric. The production of the representative final good z involves two stages, both under the control of the final good producer. In the first stage, workers manufacture a continuum of intermediate goods. In the second stage, these intermediates are costlessly assembled into a final good variety. Final assembly is tied to the domestic headquarters. The novel feature of this model comes into play at the first stage: Firms are free to produce any one intermediate either at home or offshore. Hence the geographic location of every intermediate is endogenous. This opens up a new channel for the transmission of shocks across countries.

First stage of production

Firms need a continuum of intermediates with mass unity to produce a variety of the final good. To facilitate comparison with Grossman and Rossi-Hansberg (2008*b*), I refer to the corresponding production activities as *tasks*.[4]

Crucially, the production of every intermediate can be located in any of the two countries. In contrast to the usual Armington assumption, a given intermediate produced offshore is a perfect substitute for the same intermediate produced at home. *Offshoring* occurs if a domestic firm manufactures some intermediates abroad. Since each intermediate has to be shipped physically or transferred electronically to the headquarters, firms can decide on the location of an individual intermediate independently from the location of the other intermediates. Notice that workers are barred from international migration.

---

[4]Hence "task" refers to an activity, while "intermediate" stands for the product of this activity.

The production technology for intermediates is linear in labor. Suppose the representative firm decides to produce intermediate $i \in [0, 1]$ in the home country. The unit cost of intermediate i produced at home is simply:

$$MC_{H,t}(i, z) = a_H(i)w_t. \tag{4.1}$$

Here, w_t is the domestic wage rate in period t and $a_H(i)$ is the unit labor requirement associated with the production of intermediate i *at home*. In general, the unit labor requirements may differ across tasks.

If, however, the firm decides to locate intermediate i *offshore*, it hires foreign workers at foreign wages. Denoting by w_t^* the foreign wage rate and by S_t the nominal exchange rate, the unit cost of performing task i offshore and shipping the produced intermediate back to the home country is:

$$MC_{F,t}(i, z) = \tau(i)a_F(i)S_t w_t^* \qquad (\tau(i) \geq 1). \tag{4.2}$$

Here, $a_F(i)$ is the labor coefficient corresponding to task i in Foreign and $\tau(i)$ denotes task-specific offshoring costs, including transport costs.

For future reference, let $\alpha(i) \equiv \tau(i)a_F(i)/a_H(i)$ be the *offshoring curve*. For each task $i \in [0, 1]$, this curve captures the effective labor requirement (including distance costs) associated with sourcing task i from overseas, relative to the corresponding labor requirement in the case of domestic production. Hence a lower $\alpha(i)$ is more favorable to offshoring. Let the individual tasks be ordered on the unit interval such that tasks are closer to zero for which offshoring is relatively profitable for domestic firms. This implies $\alpha'(i) \geq 0$. I will impose the stricter assumption that $\alpha(i)$ is continuous and strictly increasing in i.

Two scenarios are nested in this generic notation. The first scenario closely follows Grossman and Rossi-Hansberg (2008*b*):

Scenario S.1 *Task-specific offshoring costs.* *Offshoring costs $\tau(i)$ are task-specific, but identical for domestic and foreign firms. All tasks are ordered along the unit interval such that $\tau(i)$ is strictly increasing in i: $\tau'(i) > 0$. (I also assume $\tau(0) = 1$.) At the same time, the representative firm encounters the same production technology for individual tasks at home and offshore. For the sake of simplicity, production-related unit labor requirements are assumed to be identical for all tasks and equal to unity: $a_H(i) = a_F(i) = 1 \quad \forall i \in [0, 1]$. The preceding assumptions imply that $\alpha(i) = \alpha^*(i)$.*

In Scenario S.1, the idea is that some production stages are more easily located far away from the headquarters. Some tasks lend themselves to offshoring, because they can be easily monitored and coordinated with other tasks from a distance (e.g. typewriting). Other tasks, however, might be hardly offshorable, because

they require geographical or cultural proximity to the firm's headquarters. Think of marketing services or guarding a firm's domestic premises. Artificial trade barriers, such as tariffs on trade in intermediates, can also play a role. Technically, these offshoring costs effectively raise the unit labor requirement associated with foreign sourcing. Factor price differentials can be the only motivation for offshoring in scenario S.1 and they have to be large enough to compensate for distance costs.

In the second scenario, production technology varies across tasks and countries, while offshoring costs are identical for all tasks. Hence offshoring is driven by cross-country differences in production technology:

Scenario S.2 *Country and task-specific labor productivity. Offshoring costs are absent ($\tau(i) = 1$ for all i), while production technology is task-specific. The unit labor requirements associated with a given task at home and offshore, $a_H(i)$ and $a_F(i)$, may differ. Firms always face the unit labor requirements prevailing in the country of production: $a_H(i) = a_H^*(i)$ and $a_F(i) = a_F^*(i)$. Let all tasks be ordered along the unit interval such that $a_F(i)/a_H(i)$ is upward-sloping. The preceding assumptions together imply that $\alpha(i) = 1/\alpha^*(i)$.*

The two scenarios are clearly not isomorphic. While domestic and foreign firms share the same offshoring curve in Scenario S.1, the offshoring curves are mirror images of each other in Scenario S.2. The reason for this difference is that, similar to Grossman and Rossi-Hansberg (2008*b*), I assume that offshoring costs $\tau(i)$ are determined by characteristics inherent to each task, such as whether tasks can be seen as routine tasks or whether they are easily codified. Under these circumstances, it would be unreasonable to posit that the $\tau(i)$ is sloping upwards in one country and downwards in the other. Only in that case would the two scenarios be isomorphic.

Of course, one could also think of a combination of the two scenarios in which both transport costs and production technology are task-specific and the latter differs across countries. Such hybrid scenarios could easily be implemented as long as the offshoring curve $\alpha(i)$ is well-behaved. However, in the following I will focus on the two extreme scenarios outlined above.

Crucially, $\alpha(i)$ varies across tasks in both scenarios, allowing me to pin down the optimal location of every task (see Section 4.2.1). For the time being, however, I take as given that tasks are located optimally. Let the marginal task that is being offshored, i.e. the extensive margin of offshoring, be denoted by $I_t(z)$. Also, recall that the individual tasks are ordered on the unit interval such that tasks for which offshoring is relatively profitable are closer to zero. Then all tasks in the range $(I_t(z), 1]$ are performed at home, while the remaining tasks are located at offshore plants.[5]

---

[5]If, in Scenario S.2, distance costs were non-zero (but identical for all tasks), some tasks would

Final stage of production

In the final stage of production the representative firm costlessly bundles together the continuum of intermediates produced in the first stage. Final assembly is characterized by constant returns to scale and a constant elasticity of substitution, λ. This elasticity is the same for all intermediates, regardless of their country of origin. I rule out the case of perfect substitutability. Each intermediate is equally important, meaning that individual intermediates enter the cost function with identical weight (normalized to unity). Note that it is important to distinguish between the substitutability of two different tasks (which is less than perfect and equal to λ) and the substitutability of a given intermediate i produced at home and the same intermediate produced abroad (which is perfect).

The unit cost function of the representative firm is given by:[6]

$$
\begin{aligned}
MC_t(z) &= \frac{1}{Z_{A,t}} \left[\int_0^1 \left(\min \left\{ MC_{F,t}(i,z), MC_{H,t}(i,z) \right\} \right)^{1-\lambda} \mathrm{d}\,i \right]^{\frac{1}{1-\lambda}} \\
&= \frac{1}{Z_{A,t}} \left[\int_0^{I_t(z)} \left(MC_{F,t}(i,z) \right)^{1-\lambda} \mathrm{d}\,i + \int_{I_t(z)}^1 \left(MC_{H,t}(i,z) \right)^{1-\lambda} \mathrm{d}\,i \right]^{\frac{1}{1-\lambda}}.
\end{aligned}
\tag{4.3}
$$

The second equality follows from the fact that tasks are located optimally. $Z_{A,t}$ denotes a stochastic technology shock.

Plugging the unit cost functions corresponding to the first stage of production, i.e. equations (4.1) and (4.2), into (4.3) gives:

$$
MC_t(z) = \frac{1}{Z_{A,t}} \left[\int_0^{I_t(z)} \left(\tau(i) a_F(i) S_t w_t^* \right)^{1-\lambda} \mathrm{d}\,i + \int_{I_t(z)}^1 \left(a_H(i) w_t \right)^{1-\lambda} \mathrm{d}\,i \right]^{\frac{1}{1-\lambda}}. \tag{4.4}
$$

The conditional demand for labor at home and offshore, respectively, is:

$$
L_{H,t}(z) = \frac{Y_t(z)}{Z_{A,t}} \left(\frac{Z_{A,t} MC_t(z)}{w_t} \right)^{\lambda} \int_{I_t(z)}^1 \left(a_H(i) \right)^{1-\lambda} \mathrm{d}\,i \tag{4.5}
$$

$$
L_{F,t}(z) = \frac{Y_t(z)}{Z_{A,t}} \left(\frac{Z_{A,t} MC_t(z)}{S_t w_t^*} \right)^{\lambda} \int_0^{I_t(z)} \left(\tau(i) a_F(i) \right)^{1-\lambda} \mathrm{d}\,i. \tag{4.6}
$$

---

not be traded in equilibrium.

[6]It would be straightforward to introduce adjustment costs on the extensive margin of offshoring: $\widetilde{MC}_t(z) = \frac{\Gamma_{I,t}(z)}{Z_{A,t}} MC_t(z)$, where $\Gamma_{I,t}(z) = 1 + \frac{\phi_I}{2} \left[\frac{I_t(z)}{I_{t-1}} - 1 \right]^2$ ($\phi_I \geq 0$). The idea would be that swiftly setting up or closing down offshore production facilities is costlier than gradual adjustment. To simplify the optimization problem of the firm, it is convenient to let adjustment costs depend on the (lagged) *aggregate* level of the extensive margin of offshoring, I_{t-1}. However, the impulse response analysis will show that the adjustments in the extensive margin of offshoring are rather small, even in the absence of adjustment costs. Therefore, I abstract from adjustment costs to simplify the exposition.

Here, $L_{F,t}(z)$ is the amount of foreign labor needed by firm z to produce tasks $[0, I_t(z)]$ offshore and $L_{H,t}(z)$ is the quantity of domestic labor needed for tasks $(I_t(z), 1]$. $Y_t(z)$ is the quantity of the final good variety z produced in period t. A more detailed look at the production module of the model is provided in Section 4.5.1 in the appendix.

Pinning down the extensive margin

Which intermediates should be produced offshore? Obviously, the representative firm will relocate all tasks that can be sourced at lower cost from offshore plants. The total cost of a given intermediate is made up of production costs and, in Scenario S.1, offshoring costs. This calculus is reflected in the first-order condition with respect to $I_t(z)$:

$$\alpha(I_t(z)) = \frac{w_t}{S_t w_t^*}. \tag{4.7}$$

This *marginal offshoring condition* states that the cost of producing the marginal intermediate $I_t(z)$ at home must be identical to the cost of sourcing it from an offshore plant, provided that an interior solution exists.[7] A very similar expression holds in the static model by Grossman and Rossi-Hansberg (2008*b*). When deciding on the location of individual production stages, the representative firm will generally take into account three factors: the relative wage rate (right-hand side) as well as productivity differences and offshoring costs, as summarized by the offshoring curve $\alpha(i)$ (left-hand side). In general, sourcing a given task i from offshore will be profitable only if the unit cost is lower at foreign plants, i.e. $\alpha(i) \leq w_t/S_t w_t^*$. More specifically, in Scenario S.1, in which technology is the same in both countries, the representative firm will find it optimal to offshore only tasks that are associated with relatively low distance costs and produce all remaining intermediates at home. In Scenario S.2, all tasks for which Foreign enjoys an absolute cost advantage in production will be offshored.

The foreign representative firm is also free to produce intermediates in Home and therefore faces a similar optimization problem. The foreign offshoring curve $\alpha^*(i)$ is defined over the same ordered set of tasks as Home's and the marginal offshoring condition is given by:

$$\frac{1}{\alpha^*(I_t^*(z))} = \frac{w_t}{S_t w_t^*}. \tag{4.8}$$

---

[7]Formally, recall that α is continuous and strictly increasing in i. Suppose $w_t > \alpha(0)S_t w_t^*$ and $w_t < \alpha(1)S_t w_t^*$. Then, by the intermediate value theorem, there is an intermediate $I_t(z) \in (0,1)$ that satisfies $w_t = \alpha(I_t(z))S_t w_t^*$.

Foreign firms will offshore all tasks for which $1/\alpha^*(i) \geq w_t/S_t w_t^*$, where $\alpha^*(i) \equiv \tau(i)a_H(i)/a_F(i) = \alpha(i)a_H(i)/a_F(i)$. In Scenario S.1, this implies that $1/\alpha(i) \geq w_t/(S_t w_t^*)$. In Scenario S.2, we have $\alpha(i) \geq w_t/(S_t w_t^*)$.

In Scenario S.1, in which $\alpha(i) = \alpha^*(i)$, offshoring must be a one-way phenomenon. The reason is that only firms from the high-wage country will ever find it optimal to incur offshoring costs to relocate tasks to the other country. Technically, (4.7) and (4.8) simply cannot be fulfilled at the same time, unless wages are equalized across countries, in which case there is no offshoring (since $\tau(0) = 1$ and $\tau'(i) > 0$). If the countries are symmetric in steady state, offshoring can only occur as a temporary response to transitory wage differentials in the face of macroeconomic shocks. This is arguably a poor representation of the real-world offshoring patterns.

In Scenario S.2, by contrast, two-way offshoring is possible. In this case, $\alpha^*(i)$ is strictly *falling* in i and we have $\alpha(i) = 1/\alpha^*(i)$ due to cross-country differences in production technology. Figure 4.1 depicts the resulting pattern of international specialization. Domestic firms relocate all tasks $[0, I_t]$ to Foreign, while performing the other tasks at home. Foreign firms offshore tasks $(I_t, 1]$ to Home and keep the others at their headquarters. Hence tasks $[0, I_t)$ are performed only in Home and tasks $[I_t, 1]$ only in Foreign. The higher the domestic wage rate relative to the foreign one, the more tasks are being performed offshore, ceteris paribus. Analogously, all other things being equal, an across-the-board increase in relative productivity at offshore plants translates into more extensive offshoring. This model variant also allows for the presence of offshoring even in a symmetric steady state (apart from the fact that each country offshores another part of the task continuum, which is inconsequential).

Price Setting

Having arranged production efficiently, the representative domestic firm has to choose the optimal price of variety z, $p_{H,t}(z)$. In the tradition of Rotemberg (1982), individual goods prices are costly to adjust. More specifically, adjustment costs rise with the rate of change in firm z's price relative to the past rate of change in the price index P_H corresponding to the bundle of all domestic varieties:

$$\Gamma_{P,t}(z) \equiv \frac{\phi_P}{2} \left(\frac{p_{H,t}(z)/p_{H,t-1}(z)}{P_{H,t-1}/P_{H,t-2}} - 1 \right)^2 \qquad (\phi_P \geq 0). \qquad (4.9)$$

Adjustment costs are expressed in terms of forgone profits, as in Laxton and Pesenti (2003). For convenience, disbursements ensuing from price adjustments are paid directly to the domestic households in a lump-sum fashion.

With price adjustment costs as specified in (4.9) the choice of today's price affects tomorrow's profit due to the fact that setting a different price tomorrow
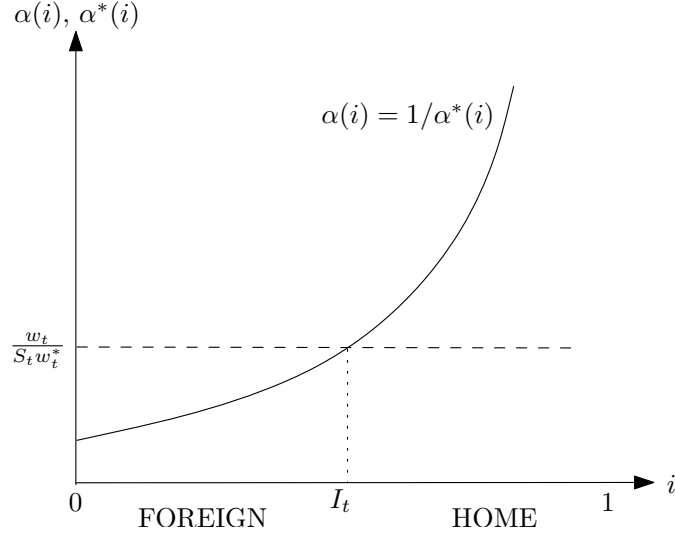
Figure 4.1 Pinning down the extensive margin of offshoring with country and task-specific labor productivity (Scenario S.2).

will be costly. More specifically, the representative firm maximizes expected future profits,

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \zeta_{0,t} \left[(1 - \Gamma_{P,t}(z)) \left(p_{H,t}(z) - MC_t(z) \right) Y_t(z) \right] \right\}, \tag{4.10}$$

where $\zeta_{0,t}$ is the households' stochastic discount factor between periods 0 and t (with $\zeta_{0,0} = 1$). Firms use this measure to discount future profits, because they are entirely owned by domestic households.

The firm takes into account price adjustment costs, as specified in (4.9), and a downward-sloping demand curve:

$$Y_t(z) = \left(\frac{p_{H,t}(z)}{P_{H,t}} \right)^{-\theta} Y_t. \tag{4.11}$$

Here, Y_t is the aggregate demand for domestic final goods varieties and θ is the elasticity of substitution between domestic varieties, as determined by household preferences (see the following section).

The first-order condition for this dynamic maximization problem is:

$$[1 - \Gamma_{P,t}(z)] \left[p_{H,t}(z)(1 - \theta) + \theta MC_t(z) \right] = \frac{\partial \Gamma_{P,t}(z)}{\partial p_{H,t}(z)} \left[p_{H,t}(z) - MC_t(z) \right] p_{H,t}(z)$$

$$+ \mathbb{E}_t \left\{ \lambda_{t,t+1} \frac{\partial \Gamma_{P,t+1}(z)}{\partial p_{H,t}(z)} \frac{Y_{t+1}(z)}{Y_t(z)} \left[p_{H,t+1}(z) - MC_{t+1}(z) \right] p_{H,t}(z) \right\}.$$

$$\tag{4.12}$$

Here, I have used the fact that $\lambda_{0,t+1}/\lambda_{0,t} \equiv \lambda_{t,t+1}$. In the absence of price adjustment costs ($\phi_P = 0$), equation (4.12) collapses to the standard markup rule: $p_{H,t}(z) = \frac{\theta}{\theta-1} MC_t(z)$. The same is true in a non-stochastic steady state.

Firms set export prices in their own currency and there are no impediments to trade in final goods. Hence, by the law of one price, foreign consumers pay $p^*_{H,t}(z) = p_{H,t}(z)/S_t$ for a domestic variety z.

4.2.2 Households

The household module of the model is quite standard and leans on the workhorse DSGE model by Laxton and Pesenti (2003).

The world is populated by a continuum of infinitely-lived households with mass unity. A fraction n lives in Home. The expected lifetime utility of the representative household $j \in [0, n]$ is given by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[U(C_t(j)) - V(L_t(j)) \right] \qquad (0 < \beta < 1), \tag{4.13}$$

where β is the subjective discount factor.

Consumption preferences exhibit external habit persistence:

$$U(C_t(j)) = \frac{Z_{C,t} \left[C_t(j) - \gamma C_{t-1} \right]^{1-\sigma}}{1-\sigma} \qquad (0 < \gamma < 1). \tag{4.14}$$

Here, $C_t(j)$ denotes the representative household's consumption at date t and C_{t-1} is aggregate consumption in period $t-1$. The shock term $Z_{C,t}$ is common to all households. Throughout this text, a Z denotes an exogenous shock variable. The underlying stochastic processes are described below.

Disutility from labor is specified as

$$V(L_t(j)) = \frac{L_t(j)^{1+\mu}}{1+\mu}, \tag{4.15}$$

where $L_t(j)$ is labor supply in t.

Intra-temporal optimization

The representative household consumes all varieties of domestic and foreign goods. For final goods, I adopt the simplifying Armington assumption, since the main focus of this chapter is on vertical linkages in production. Hence the real consumption index $C_t(j)$ is defined as:

$$C_t(j) = \left[\omega^{\frac{1}{\nu}} C_{H,t}(j)^{\frac{\nu-1}{\nu}} + (1-\omega)^{\frac{1}{\nu}} C_{F,t}(j)^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}} \qquad (0 < \omega < 1). \tag{4.16}$$

Here, ω is the weight of domestic goods in consumption. Parameter ν denotes the elasticity of substitution between the bundle of domestic varieties, $C_{H,t}(j)$, and the bundle of foreign varieties, $C_{F,t}(j)$. These bundles, in turn, are given by

$$C_{H,t}(j) = \left[\left(\frac{1}{n} \right)^{\frac{1}{\theta}} \int_0^n c_{H,t}(j,z)^{\frac{\theta-1}{\theta}} \, \mathrm{d}z \right]^{\frac{\theta}{\theta-1}} \tag{4.17}$$

$$C_{F,t}(j) = \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\theta}} \int_n^1 c_{F,t}(j,z)^{\frac{\theta-1}{\theta}} \, \mathrm{d}z \right]^{\frac{\theta}{\theta-1}}, \tag{4.18}$$

where θ is the elasticity of substitution between individual varieties of the same origin (with $\theta > \nu$).

In each period the representative household decides on the optimal pattern of consumption. From the static optimization problem of the representative household j, one easily derives j's goods demand:

$$C_{H,t}(j) = \omega \left(\frac{P_{H,t}}{P_t} \right)^{-\nu} C_t(j) \tag{4.19}$$

$$C_{F,t}(j) = (1 - \omega) \left(\frac{P_{F,t}}{P_t} \right)^{-\nu} C_t(j) \tag{4.20}$$

$$c_{H,t}(j,z) = \frac{1}{n} \left(\frac{p_{H,t}(z)}{P_{H,t}} \right)^{-\theta} C_{H,t}(j) \tag{4.21}$$

$$c_{F,t}(j,z^*) = \frac{1}{1-n} \left(\frac{p_{F,t}(z^*)}{P_{F,t}} \right)^{-\theta} C_{F,t}(j). \tag{4.22}$$

Here, $P_{H,t}$ and $P_{F,t}$ are domestic price indices corresponding to $C_{H,t}(j)$ and $C_{F,t}(j)$, respectively. Analogously, $p_{H,t}(z)$ and $p_{F,t}(z^*)$ are the domestic-currency prices of domestic variety $z \in [0,n]$ and foreign variety $z^* \in [n,1]$, respectively. Finally, $c_{H,t}(j,z)$ and $c_{F,t}(j,z^*)$ are the quantities consumed of z and z^*.

The consumption-based price index is defined as the minimum expenditure that is necessary to purchase one unit of the consumption aggregate:

$$P_t = \left[\omega P_{H,t}^{1-\nu} + (1-\omega) P_{F,t}^{1-\nu} \right]^{\frac{1}{1-\nu}}. \tag{4.23}$$

Price sub-indices can be computed as:

$$P_{H,t} = \left[\frac{1}{n} \int_0^n p_{H,t}(z)^{1-\theta} \, \mathrm{d}z \right]^{\frac{1}{1-\theta}} \tag{4.24}$$

$$P_{F,t} = \left[\frac{1}{1-n} \int_n^1 p_{F,t}(z^*)^{1-\theta} \, \mathrm{d}z^* \right]^{\frac{1}{1-\theta}}. \tag{4.25}$$

Inter-temporal optimization

The representative household j supplies labor, $L_t(j)$, at the nominal wage rate w_t. Income is also derived from beginning-of-period-t money holdings $M_{t-1}(j)$ and public transfers $T_t(j)$.

Domestic households hold three types of assets, namely shares in a mutual fund fed by the profits of all domestic firms, bonds denominated in domestic currency, and bonds denominated in foreign currency. Shares entitle to dividends $\Pi_t(j)$ at the end of period t. There is no international trade in equities. Domestic bond holdings $D_t(j)$ and foreign bond holdings $F_t(j)$ pay off their yield at the beginning of period t. The nominal interest rates i_t and i_t^* are known in period $t-1$. Domestic households holding foreign bonds pay fees to intermediaries. Following Laxton and Pesenti (2003), bond fees are paid as a fraction of the gross yield on foreign bonds and depend on Home's net asset position:[8]

$$\Gamma_{F,t} = \phi_{F1} \frac{\exp(\phi_{F2} S_{t-1} F_t/P_{t-1}) - 1}{\exp(\phi_{F2} S_{t-1} F_t/P_{t-1}) + 1}. \tag{4.26}$$

Here, we have $0 \leq \phi_{F1} \leq 1$, $\phi_{F2} > 0$, and $F_t \equiv \int_0^n F_t(j)\,\mathrm{d}j$. When Home is a net lender, bond fees rise asymptotically to ϕ_{F1} as F goes to infinity. Thus, households have to give away an increasing fraction of their gross yield. When Home is a net borrower, bond fees fall asymptotically to $-\phi_{F1}$, i.e. domestic households pay an increasing premium. This ensures that net asset positions are stationary and the economies converge asymptotically to a steady state. Also, it implies that there is a well-defined steady state with zero net asset positions, as shown by Schmitt-Grohé and Uribe (2003). Bond fees are handed back to the public in a lump-sum fashion.

Income is also spent on the consumption of final goods, $C_t(j)$, and domestic currency holdings, $M_t(j)$. As in Laxton and Pesenti (2003) and Schmitt-Grohé and Uribe (2004), consumption is subject to transaction costs $\Gamma_{C,t}(j)$ depending on the individual money velocity, $v_t(j) \equiv P_t C_t(j)/M_t(j)$:

$$\Gamma_{C,t}(j) = \phi_{C1} v_t(j) + \frac{\phi_{C2}}{v_t(j)} - 2\sqrt{\phi_{C1}\phi_{C2}}. \tag{4.27}$$

The representative household takes these costs into account when deciding on the optimal level of money holdings. Shopping costs are included in the model to create an incentive for households to hold money. For the sake of simplicity,

---

[8]A note on the time subscripts: $\Gamma_{F,t}$ lowers earnings paid on foreign bonds carried over from period $t-1$ to t. Its magnitude is determined by the aggregate level of foreign bonds held by domestic residents at the end of period $t-1$, F_t, the exchange rate, and the price level in that period.

shopping costs are transferred directly to the households in a lump-sum fashion. All in all, revenues in the amount of $R_t(j)$ accrue to household j. Notice that $R_t(j)$ includes dividends from domestic final goods producers and is treated as given by an individual household.

All this adds up to household j's flow budget constraint:

$$
\begin{aligned}
D_{t+1}(j) + S_t F_{t+1}(j) &+ M_t(j) + P_t C_t(j) \left[1 + \Gamma_{C,t}(j)\right] \\
&\leq (1 + i_t) D_t(j) + (1 + i_t^*) \left(1 - \Gamma_{F,t}\right) S_t F_t(j) + M_{t-1}(j) \\
&+ T_t(j) + R_t(j) + w_t L_t(j).
\end{aligned}
\tag{4.28}
$$

The representative household maximizes the expected lifetime utility (4.13) subject to the sequence of flow budget constraints. At any date t, the optimality conditions with respect to consumption and bond holdings may be written as:

$$
1 = (1 + i_{t+1})\mathbb{E}_t \zeta_{t,t+1} = (1 + i_{t+1}^*)(1 - \Gamma_{F,t+1})\mathbb{E}_t \left\{ \zeta_{t,t+1} \frac{S_{t+1}}{S_t} \right\}.
\tag{4.29}
$$

Notice that the stochastic discount factor between periods t and $t + 1$ is given by

$$
\zeta_{t,t+1} \equiv \frac{\beta P_t U'(C_{t+1}(j)) \left[1 + \Gamma_{C,t}(j) + \Gamma'_{C,t}(j) v_t(j)\right]}{P_{t+1} U'(C_t(j)) \left[1 + \Gamma_{C,t+1}(j) + \Gamma'_{C,t+1}(j) v_{t+1}(j)\right]}
\tag{4.30}
$$

and that $\Gamma'_{C,t}(j) \equiv \partial \Gamma_{C,t}(j)/\partial v_t(j)$. In a non-stochastic, zero-inflation steady state, the nominal interest rates are equalized.

Labor supply is given by:

$$
L_t(j)^\mu = \frac{Z_{C,t} w_t}{P_t \left(C_t(j) - \gamma C_{t-1}\right)^\sigma}.
\tag{4.31}
$$

The demand for real balances depends positively on the consumption level and negatively on the nominal interest rate:

$$
\frac{M_t(j)}{P_t} = C_t(j) \sqrt{\frac{\phi_{C1}}{\phi_{C2} + \frac{i_{t+1}}{1+i_{t+1}}}}.
\tag{4.32}
$$

The following transversality condition also applies:

$$
\lim_{t \to \infty} \mathbb{E}_0 \left\{ \zeta_{0,t} \left[M_{t-1}(j) + (1 + i_t) D_t(j) + (1 + i_t^*) \left(1 - \Gamma_{F,t}\right) S_t F_t(j)\right] \right\} = 0.
\tag{4.33}
$$

4.2.3 Government

Finally, aggregate public transfers, $T_t \equiv \int_0^n T_t(j) \, \mathrm{d}\,j$, enter the government's budget constraint:

$$T_t + P_{H,t}G_t = M_t - M_{t-1}. \tag{4.34}$$

Here, M_t is total money supply in period t. Government purchases, G_t, and lump-sum transfers must add up to seigniorage earnings. The government consumes only domestic goods and the elasticity of substitution between varieties, θ, is identical to that of private households.

4.2.4 Aggregation and market clearing

Given the symmetry across households and across firms, aggregated equations are straightforward to derive and therefore omitted. To derive a current account equation, notice that aggregate private transfers, R_t, are made up of dividends and rebates of transaction costs:

$$R_t = P_{H,t}Y_t - w_t L_{H,t} - S_t w_t^* L_{F,t} + \Gamma_{F,t}(1 + i_t^*)S_t F_t. \tag{4.35}$$

The current account equation boils down to:

$$\begin{aligned} D_{t+1} + S_t F_{t+1} + P_{H,t}G_t + P_t C_t \left(1 + \Gamma_{C,t}\right) \\ = (1 + i_t)D_t + (1 + i_t^*)S_t F_t + P_{H,t}Y_t - S_t w_t^* L_{F,t} + w_t L_{H,t}^*. \end{aligned} \tag{4.36}$$

In equilibrium, bonds must be in zero net supply: $D_t + D_t^* = 0$ and $F_t + F_t^* = 0$. Clearing of domestic and foreign labor markets requires $L_t = L_{H,t} + L_{H,t}^*$ and $L_t^* = L_{F,t}^* + L_{F,t}$. Here, $L_{F,t}^*$ and $L_{H,t}^*$ stand for the foreign firms' labor demand in Foreign and Home, respectively. Goods markets are in equilibrium if

$$Y_t = C_{H,t}\left(1 + \Gamma_{C,t}\right) + C_{H,t}^*\left(1 + \Gamma_{C,t}^*\right) + G_t \tag{4.37}$$

$$Y_t^* = C_{F,t}^*\left(1 + \Gamma_{C,t}^*\right) + C_{F,t}\left(1 + \Gamma_{C,t}\right) + G_t^*. \tag{4.38}$$

Clearing conditions for the money markets are merely bookkeeping. Furthermore, one clearing condition is redundant by Walras' law.

4.2.5 Stochastic processes

The domestic economy is confronted with shocks to production technology (Z_A), consumption preferences (Z_C), money supply (M) and government purchases ($g \equiv G/Y$). The stochastic processes are specified as follows:

$$\log(u_t) = (1 - \rho_u) \log(u_0) + \rho_u \log(u_{t-1}) + z_{u,t}. \tag{4.39}$$

Here, $u \in \{g, M, Z_A, Z_C\}$ and $0 < \rho_u < 1$. Furthermore, u_0 denotes the corresponding steady state level, while $z_{u,t}$ is Gaussian white noise.

4.3 The role of the extensive margin in macroeconomic dynamics

Having set up a model with truly endogenous vertical linkages, I now study the role of the extensive margin of offshoring in macroeconomic dynamics. To this end, I compare the dynamics of the model under two different assumptions. In the first case, the intensive and extensive margins of offshoring are endogenous, as described in the previous section. In the second case, by contrast, the extensive margin of offshoring is exogenously fixed at 0.5. This means that both countries always import exactly one-half of the continuum of intermediates from abroad. Essentially, firms treat domestic and foreign intermediates as two distinct bundles and only vary the input quantities of these bundles. The equations presented in the previous section continue to hold, with the exception of the marginal offshoring condition (4.7), which disappears. Both variants start out from the same (symmetric) non-stochastic steady state. Since the model has no closed-form solution (regardless of whether the extensive margin is endogenous or not), it is linearized around the steady state and solved numerically.[9]

4.3.1 Calibration

An analysis of the dynamic properties of the model requires that the offshoring curves, $\alpha(i)$ and $\alpha^*(i)$, be specified. In the following, I concentrate on Scenario S.2 in which offshoring is driven by differences in task-specific production technology. This scenario has the advantage of allowing for offshoring in a symmetric steady state. Without loss of generality, then, let all tasks be ordered such that $\alpha(i)$ is increasing in i. To simplify the analysis, I adopt the stricter assumption that all tasks have different labor coefficients. To keep matters as simple as possible, I assume $\tau(i) = 1$, $a_H(i) = a_H^*(i) = \exp[\psi(1-i)]$ and $a_F(i) = a_F^*(i) = \exp(\psi i)$. This implies the following functional form of the offshoring curve:

$$\alpha(i) \equiv \frac{\tau(i)a_F(i)}{a_H(i)} = \exp\left[\psi(2i-1)\right]. \tag{4.40}$$

Recall that, in Scenario S.2, the foreign offshoring curve is simply a mirror image of the domestic one: $\alpha(i) = 1/\alpha^*(i)$. Plugging this functional form into equations

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[9]The results are based on Dynare, a free software package designed for the analysis of DSGE models. It is available online: http://www.dynare.org.

(4.7) and (4.8) yields:

$$I_t = 0.5 \left[1 + \frac{1}{\psi} \log \left(\frac{w_t}{S_t w_t^*} \right) \right] \tag{4.41}$$

$$I_t^* = 0.5 \left[1 - \frac{1}{\psi} \log \left(\frac{w_t}{S_t w_t^*} \right) \right]. \tag{4.42}$$

Notice that the preceding equations imply that $I_t = 1 - I_t^*$ for all t. Hence the tasks offshored by Home are exactly those produced locally by Foreign, and vice versa, due to the absence of offshoring costs.

Table 4.1 summarizes the baseline calibration. For the sake of simplicity, I assume that the two countries are perfectly symmetric in the initial steady state. This implies that both countries import exactly one-half of the continuum of intermediates from abroad ($I_0 = I_0^* = 0.5$). In the baseline calibration, I assume $\psi = 1$. The elasticity of substitution between individual intermediates, λ, is set to 1.5, a fairly standard value in the macroeconomic literature.

Parameter	Value
Preferences	
β	$1.03^{-0.25}$
γ	0.95
σ	1/3
μ	2.5
ν	5
ω	0.5
θ	6
Technology	
λ	1.5
ψ	1.0
$a_H(i)$	$\exp[\psi(1-i)]$
$a_F(i)$	$\exp(\psi i)$
$\alpha(i)$	$\exp[\psi(2i-1)]$

Parameter	Value
Frictions	
ϕ_{C1}	0.011
ϕ_{C2}	0.075
ϕ_{F1}	0.05
ϕ_{F2}	0.1
ϕ_P	50
Forcing processes	
ρ_A	0.95
ρ_g	0.95
ρ_C	0.95
ρ_L	0.95
ρ_M	0.9

Table 4.1 Baseline calibration. The calibration is perfectly symmetric for both countries.

As mentioned above, the demand side of this model leans on Laxton and Pesenti (2003), who calibrate their model to euro area and Czech data. In the following, I largely follow the calibration referring to the euro area economy. To start with, the subjective discount factor is $\beta = 1.03^{-0.25}$. Given identical discount factors, nominal interest rates are equalized in steady state and steady-state foreign asset positions are zero, i.e. $D_0 = F_0 = 0$. The intra-temporal elasticity of substitution

between individual varieties is $\theta = 6$. This implies a steady-state markup factor of $\theta/(\theta - 1) = 1.2$. The elasticity between domestic and foreign goods, absent in Laxton and Pesenti (2003), is somewhat lower: $\nu = 5$. I also adopt the parameterization for the shopping cost parameters: $\phi_{C1} = 0.011$ and $\phi_{C2} = 0.075$. As Laxton and Pesenti (2003), I opt for a combination of high habit persistence, $\gamma = 0.95$, and a relatively high elasticity of substitution, $\sigma = 1/3$. The inverse of the Frisch elasticity of labor supply is $\mu = 2.5$. Finally, the auto-correlation coefficients and standard deviations governing the shock processes are also largely taken from Laxton and Pesenti (2003).

4.3.2 Impulse response analysis

In the following, I will study the impulse responses generated by the model for a variety of standard macroeconomic shocks. For each shock, two different sets of impulse responses are considered. In the first case, the extensive margin of offshoring is fixed, as in a standard DSGE model, whereas the second model variant treats the extensive margin as an endogenous variable to be determined by the interplay of relative productivity and wages.

To start with, consider a temporary one-percent increase in domestic total factor productivity (TFP), Z_A, in the case in which the extensive margin of offshoring is exogenous. Recall that TFP only affects the bundling efficiency at the final stage of production, but has no direct impact on the first stage of production. The corresponding impulse responses are plotted in Figures 4.2-4.3 (dashed lines).[10] The temporary increase in domestic TFP immediately leads to a marked drop in the marginal cost of Home's final good and prompts domestic firms to lower the prices of their final goods varieties. The adjustment is smoothed over time due to price adjustments costs. The decline in the price of the domestic final good leads to a deterioration in Home's terms of trade (P_H/P_F), which prompts households in both countries to increase their consumption of Home's final good relative to Foreign's. Since output is demand determined, domestic firms temporarily scale up production to satisfy the increased demand. This, in turn, requires higher inputs of both domestic and foreign intermediates. Put differently, offshoring proceeds along the intensive margin. Meanwhile, domestic households increase the overall level of consumption, since the spike in domestic output is tantamount to a transitory increase in income. To smooth consumption over time, the increased income is also partially saved and lent to Foreign. International borrowing allows foreign households to increase their consumption in the short run, too, despite the

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[10]For the sake of readability, the charts show the impulse response functions only up to the 60th quarter. However, all variables revert to their initial steady state level over a longer time horizon. The slow reversion to the steady state reflects, among other things, the high degree of habit persistence and the presence of price adjustments costs.

temporary drop in foreign output. In light of the boost to short-run consumption, households in both countries seek to reduce labor supply. This is even more pronounced in Home, which is witnessing a higher increase in consumption. This inward shift in the supply of domestic labor relative to foreign labor goes hand in hand with an increase in the relative wage rate.[11] That said, the changes in relative employment and relative wages are marginal. This should not come as a surprise, since the TFP shock affects the relative labor input of domestic firms (L_H/L_F) and the relative demand for intermediates only indirectly, through the general equilibrium effects on relative wages. By contrast, the impacts of the shock on the market for final goods are direct and larger in magnitude.

How does the model respond to the same TFP shock if the extensive margin of offshoring is endogenous? Final goods producers are now free to switch between domestic and foreign sourcing of every individual intermediate. The solid lines in Figures 4.2-4.3 show the corresponding model dynamics. For the overwhelming majority of variables - including output, employment, consumption and the consumption price index - the impulse responses are almost indistinguishable from those in the model with exogenous I. What is more, the adjustment in the extensive margin itself is very small. The extensive margin of offshoring increases only marginally, meaning that a larger range of products is being imported from Foreign. This relocation of production activities is triggered by the - marginal - increase in the relative wage rate, which renders production in Foreign more attractive. The rise in the extensive margin, in turn, further attenuates the increase in the relative wage rate, as it shifts the firms' labor demand towards foreign workers. The tepid response of the extensive margin is reassuring, since larger short-run variations in the extensive margin of offshoring would arguably be at odds with reality. Firms are unlikely to vigorously switch back and forth between domestic and foreign sourcing over the business cycle. Remarkably, however, the low responsiveness of the extensive margin in the model does not rely on fixed costs of offshoring or sourcing frictions.

The simultaneous increases in the extensive and intensive margins together result in higher imports of foreign intermediates, X_F. The increase in inputs of foreign intermediates relative to domestic ones is more pronounced than in the model with exogenous I. This is also evident from the following relationship (derived in Section 4.5.1 in the appendix):

$$\frac{X_{F,t}}{X_{H,t}} = \left(\frac{w_t}{S_t w_t^*}\right)^\lambda \left[\frac{\int_{I_t}^1 a_H(i)^{1-\lambda}\,\mathrm{d}\,i}{\int_0^{I_t}(\tau(i)a_F(i))^{1-\lambda}\,\mathrm{d}\,i}\right]^{\frac{\lambda}{1-\lambda}}. \tag{4.43}$$

If the extensive margin is exogenous, the second term on the right-hand side is a

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[11]Note that the (aggregate) relative labor demand and supply functions are only implicitly defined.

constant. Firms then respond to a given increase in the relative wage rate, w/Sw^*, by using relatively more foreign intermediates, with an elasticity of substitution equal to λ. If the extensive margin is endogenous, firms choose to relocate some tasks to Foreign when domestic labor becomes relatively expensive. This lowers the second term on the right-hand side of the preceding equation. As a result, the overall response of relative input quantities to a given change in the relative wage rate will be more pronounced if the extensive margin is endogenous. Of course, this is a partial equilibrium effect. In general equilibrium, the attractiveness of foreign intermediates will act to raise the demand for foreign labor, putting upward pressure on foreign wages. This effect, together with other general equilibrium effects, will act to counterbalance the initial attractiveness of foreign intermediates. A priori, it is therefore ambiguous if the relative wage rate responds more forcefully to shocks with an endogenous extensive margin. The overall impact will depend on the nature of the shock and the underlying calibration.

A similar picture also emerges for other macroeconomic shocks. Starting with a money supply shock (M), the impulse responses of the two model variants are again hardly distinguishable (see Figures 4.4-4.5). The temporary increase in domestic money supply puts downward pressure on the domestic interest rate. Against this backdrop, the representative domestic household decides to consume more and work less in the short run. The consumption price index temporarily increases. Meanwhile, foreign output declines, while foreign consumption increases with the help of funds from Home. All these adjustments take place regardless of whether firms can decide on the location of their production activities. Again, the extensive margin of offshoring itself shows only a tepid response to the transitory increase in money supply. If the extensive margin of offshoring is allowed to vary, it increases marginally on the back of a small increase in the relative wage rate.

Similar results are obtained for consumption preference shocks and government expenditure shocks. Starting with the latter, recall that an increase in g amounts to an increase in government expenditure as a share of output and that it is associated with an increase in lump-sum taxes. In the case of an exogenous extensive margin, households therefore work more and borrow from abroad to smooth consumption over time, as illustrated by Figures 4.6-4.7. Nevertheless, domestic output increases on account of higher public demand for consumption goods. Endogenizing I does not change the dynamics. Now, consider the preference shock. A positive shock to Z_C means that households temporarily derive greater utility from a given level of consumption. Since consumption transitorily becomes more attractive, households consume more in the short run (see Figures 4.8-4.9). To this end, they work more and borrow from Foreign. The extensive margin of offshoring declines slightly, since foreign workers become more expensive compared with their domestic peers. Again, the impulse responses are virtually identical for both model variants.

Next, turn to Figures 4.10-4.11, which describe the model dynamics in the face of a domestic labor supply shock. Interestingly, the differences between the impulse responses of the two model variants are now more pronounced, although only qualitatively. A positive shock to Z_L means that households experience a more pronounced disutility of labor, which is tantamount to a negative labor supply shock. Not surprisingly, the retrenchment in domestic employment exerts upward pressure on the relative wage rate. If the extensive margin of offshoring is endogenous, a wider range of intermediates is being imported in response to the increased production costs at domestic plants. The fact that Home temporarily relinquishes some tasks to Foreign, in turn, mitigates the upward pressure on the relative wage rate. Overall, the discrepancies between the impulse responses are more pronounced than for the other shocks discussed so far. This should not come as a surprise, since the labor supply shock has a more direct impact on the labor market and, thereby, the relative wage rate. The larger the response of relative labor costs, the more valuable the opportunity to vary the location of production along the extensive margin. Notwithstanding this, the impulse responses exhibit only qualitative differences.

4.3.3 Sensitivity analysis

The preceding impulse analysis suggests that the dynamics of the model with truly endogenous vertical linkages are very similar to those of the model relying on the Armington assumption. In the following, I test whether this finding is robust to variations in two key parameters: the elasticity of substitution between intermediates (λ) and the parameter governing the curvature of the offshoring curve (ψ).

First, suppose the parameter ψ is set to 0.1. A lower ψ is equivalent to a higher sensitivity of the extensive margin of offshoring to changes in the relative wage rate around the symmetric steady. Figures 4.12-4.13 show the corresponding impulse responses for the same idiosyncratic TFP shock studied in Section 4.3.2. As before, the dashed lines refer to the model with exogenous I, whereas the solid lines correspond to the model with endogenous extensive margin. It is evident that the main finding of the previous section continues to hold. To be more specific, the impulse responses are virtually the same regardless of whether the extensive margin of offshoring is endogenous or not. While the increase in the extensive margin is higher than under the baseline calibration, it remains rather small.

Second, I impose a relatively high value for the elasticity of substitution between intermediates, $\lambda = 2.5$, while the offshoring curve parameter is set back to the baseline calibration. This implies that firms' demand for intermediates is now more responsive to changes in production costs at home and abroad. However, the impulse responses in the face of a TFP shock once more turn out to be very similar

for the model with endogenous I and the model with truly endogenous vertical linkages (see Figures 4.14-4.15).

4.3.4   Summary

In summary, the impulse responses in the face of the standard shocks considered here are very similar for both model variants. This finding is very robust to changes in key model parameters. It seems fair to conclude that the dynamics of the medium-scale DSGE model are fairly similar regardless of whether the extensive margin of offshoring is endogenous or not. All shocks considered here also have in common that the extensive margin of offshoring responds only marginally even if it is, in principle, allowed to fluctuate over the business cycle. Hence, from a macroeconomic perspective, it appears to be generally acceptable to study a model with vertical linkages where the extensive margin is exogenous, even if vertical linkages and the transmission of shocks are at the heart of the analysis. After all, determining the patterns of trade endogenously is not a means in itself in macro models. According to the law of parsimony, the model with exogenous extensive margin will therefore arguably be preferable for most macroeconomic applications.

4.4   Conclusion

This chapter has shed some light on the role of the extensive margin of offshoring in macroeconomic dynamics. I constructed a medium-scale DSGE model with truly endogenous vertical linkages. The model departs from the Armington assumption underlying workhorse DSGE models in that firms are free to decide on both the intensive and extensive margins of offshoring. In the most general model variant, the extensive margin is pinned down by a trade-off between task-specific offshoring costs and task-specific technology. The underlying methodology is in the spirit of Dornbusch et al. (1977).

   In this theoretical framework, I studied how the extensive margin of offshoring affects the economy's dynamic responses to macroeconomic shocks. For this purpose, I compared the impulse responses of the model with endogenous extensive margin with a model variant where this margin is treated as exogenously given. For a variety of standard macroeconomic shocks, the impulse responses turned out to be very similar for both model variants. Moreover, the extensive margin of offshoring responded only marginally to shocks, even in the model with truly endogenous vertical linkages. The only notable difference between the dynamics of the two model variants concerns the relative wage rate. If the extensive margin is endogenous, it acts to attenuate the changes in relative wages. For instance,

an increase in domestic relative to foreign labor costs triggers a relocation of production activities towards Foreign, which exerts upward pressure on foreign wages and thereby partially offsets the initial change in relative wages. However, this mechanism has only very limited impacts on the rest of the economy.

The bottom line is that the extensive margin does not act as an important channel for the propagation of shocks in an otherwise fairly standard DSGE model. Since pinning down the patterns of trade endogenously is not a means in itself in macro models, macroeconomists are well-advised to model vertical linkages with Armington aggregators. This approach ensures a parsimonious modeling structure and simplifies the calibration. The findings of this chapter also justify ex post the modeling approach chosen in Chapter 3.

It is important to bear in mind that this analysis was exclusively focused on the role of the extensive margin of offshoring in macroeconomic dynamics. Of course, endogeneity of the extensive margin remains essential in trade models studying the longer-term patterns of international specialization.

4.5 Appendix to Chapter 4

4.5.1 Production technology

This appendix presents the dual production functions corresponding to the unit cost functions in Section 4.2. It also derives the demand for intermediates.

The production function corresponding to the unit cost function (4.3) reads as follows:

$$
\begin{aligned}
Y_t(z) &= Z_{A,t} \left(\int_0^1 x_t(i,z)^{\frac{\lambda-1}{\lambda}} \, \mathrm{d}\,i \right)^{\frac{\lambda}{\lambda-1}} \\
&= Z_{A,t} \left(X_{F,t}(z)^{\frac{\lambda-1}{\lambda}} + X_{H,t}(z)^{\frac{\lambda-1}{\lambda}} \right)^{\frac{\lambda}{\lambda-1}} .
\end{aligned}
\tag{4.44}
$$

Here, $x_t(i,z)$ is the input quantity of intermediate i. $X_{F,t}(z)$ and $X_{H,t}(z)$ are the bundles of foreign and domestic intermediates used in the production of the final good. They are defined as:

$$
X_{F,t}(z) = \left(\int_0^{I_t(z)} x_{F,t}(i,z)^{\frac{\lambda-1}{\lambda}} \, \mathrm{d}\,i \right)^{\frac{\lambda}{\lambda-1}}
\tag{4.45}
$$

$$
= \left[\int_0^{I_t(z)} \left(\frac{l_{F,t}(i,z)}{\tau(i)a_F(i)} \right)^{\frac{\lambda-1}{\lambda}} \, \mathrm{d}\,i \right]^{\frac{\lambda}{\lambda-1}}
\tag{4.46}
$$

$$
X_{H,t}(z) = \left(\int_{I_t(z)}^1 x_{H,t}(i,z)^{\frac{\lambda-1}{\lambda}} \, \mathrm{d}\,i \right)^{\frac{\lambda}{\lambda-1}}
\tag{4.47}
$$

$$
= \left[\int_{I_t(z)}^1 \left(\frac{l_{H,t}(i,z)}{a_H(i)} \right)^{\frac{\lambda-1}{\lambda}} \, \mathrm{d}\,i \right]^{\frac{\lambda}{\lambda-1}} .
\tag{4.48}
$$

It is now straightforward to derive the demand of the representative firm for the bundles of foreign and domestic intermediates:

$$
X_{F,t}(z) = \frac{Y_t(z)}{Z_{A,t}} \left(\frac{Z_{A,t} MC_t(z)}{MC_{F,t}(z)} \right)^{\lambda}
\tag{4.49}
$$

$$
X_{H,t}(z) = \frac{Y_t(z)}{Z_{A,t}} \left(\frac{Z_{A,t} MC_t(z)}{MC_{H,t}(z)} \right)^{\lambda} .
\tag{4.50}
$$

Here, I have used the following definitions:

$$
MC_{F,t}(z) = \left(\int_0^{I_t(z)} MC_{F,t}(i,z)^{1-\lambda} \, \mathrm{d}\,i \right)^{\frac{1}{1-\lambda}}
\tag{4.51}
$$

$$
MC_{H,t}(z) = \left(\int_{I_t(z)}^1 MC_{H,t}(i,z)^{1-\lambda} \, \mathrm{d}\,i \right)^{\frac{1}{1-\lambda}} .
\tag{4.52}
$$

Recall that $MC_{F,t}(i,z)$, $MC_{H,t}(i,z)$ and $MC_t(z)$ are given in equations (4.1), (4.2), and (4.3), respectively.

Relative demand for foreign intermediates is then given by:

$$\frac{X_{F,t}(z)}{X_{H,t}(z)} = \left(\frac{MC_{H,t}(z)}{MC_{F,t}(z)}\right)^{\lambda} \tag{4.53}$$

$$= \left(\frac{w_t}{S_t w_t^*}\right)^{\lambda} \left[\frac{\int_{I_t(z)}^{1} a_H(i)^{1-\lambda}\,\mathrm{d}\,i}{\int_0^{I_t(z)} \left(\tau(i)a_F(i)\right)^{1-\lambda}\,\mathrm{d}\,i}\right]^{\frac{\lambda}{1-\lambda}}. \tag{4.54}$$

4.5.2 Figures
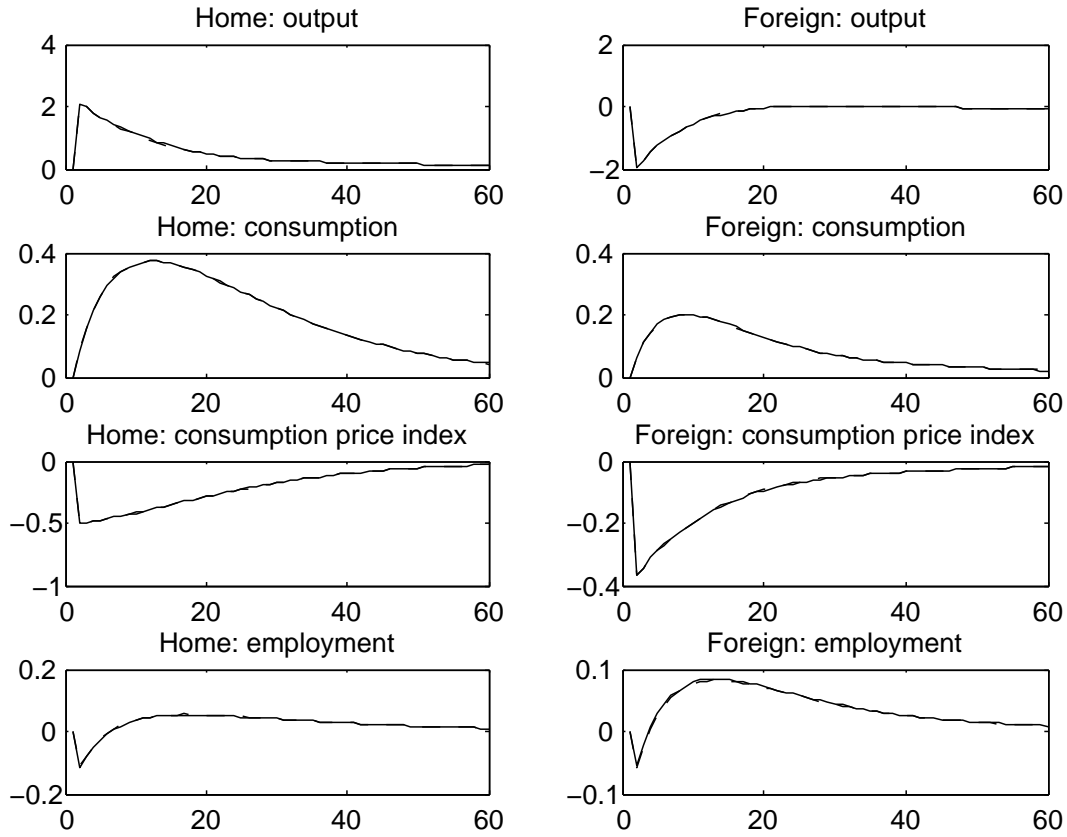
Figure 4.2 Impulse responses to a productivity shock in the home country (Z_A). All impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.
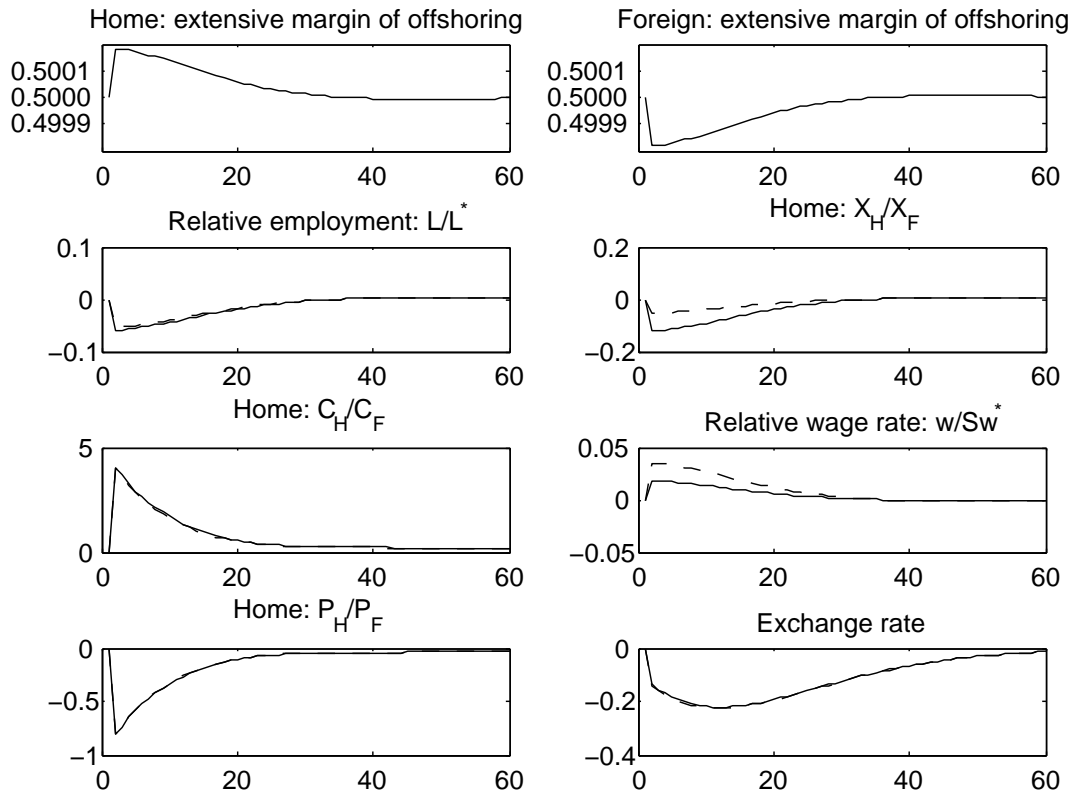
Figure 4.3 Impulse responses to a productivity shock in the home country (Z_A). The response of the extensive margin of offshoring, I, is in levels. All other impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.

Figure 4.4 Impulse responses to a monetary shock in the home country (M). All impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.

Figure 4.5 Impulse responses to a monetary shock in the home country (M). The response of the extensive margin of offshoring, I, is in levels. All other impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.

Figure 4.6 Impulse responses to a government expenditure shock in the home country (*g*). All impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous *I*.

Figure 4.7 Impulse responses to a government expenditure shock in the home country (g). The response of the extensive margin of offshoring, I, is in levels. All other impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.
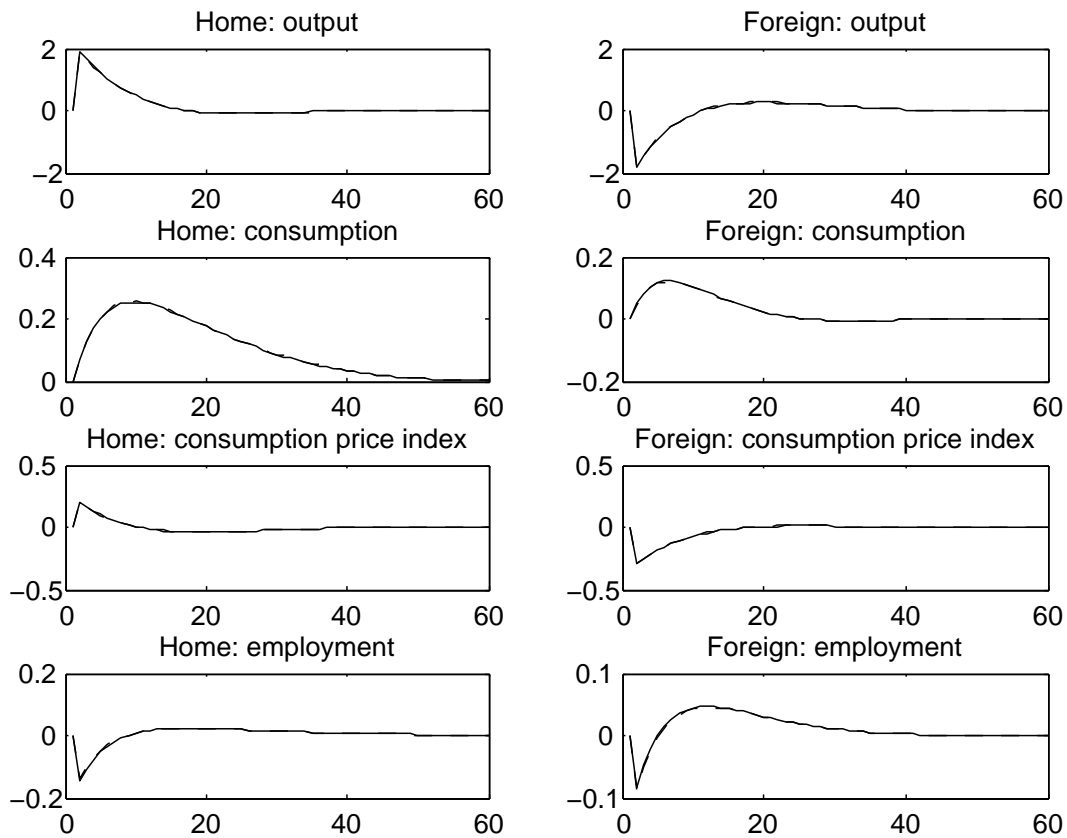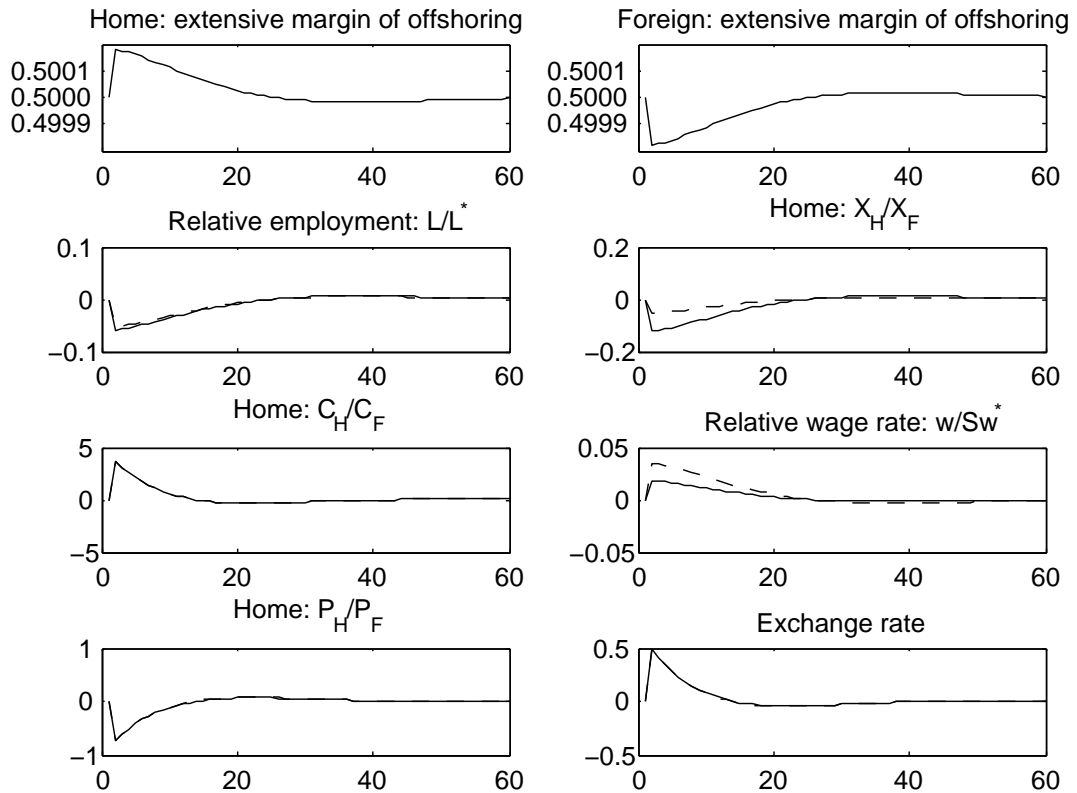
Figure 4.8 Impulse responses to a consumption shock in the home country (Z_C). All impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.

Figure 4.9 Impulse responses to a consumption shock in the home country (Z_C). The response of the extensive margin of offshoring, I, is in levels. All other impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.
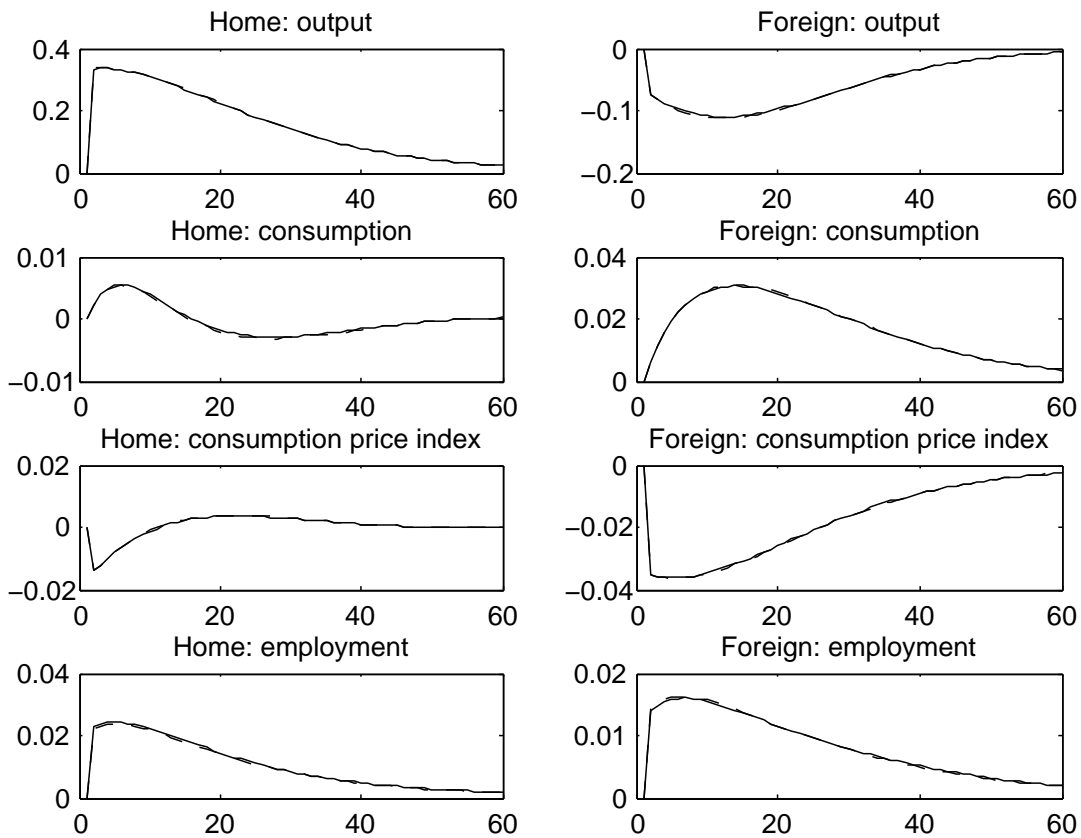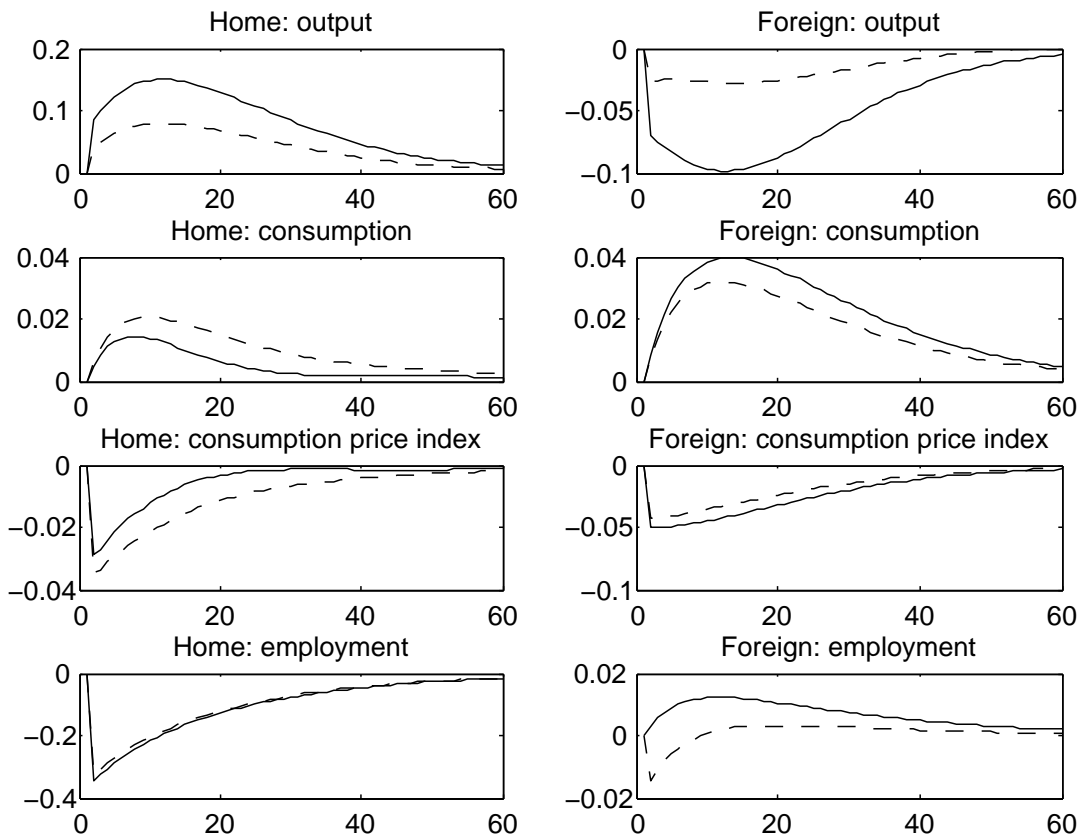
Figure 4.10 Impulse responses to a labor supply shock in the home country (Z_L). All impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.
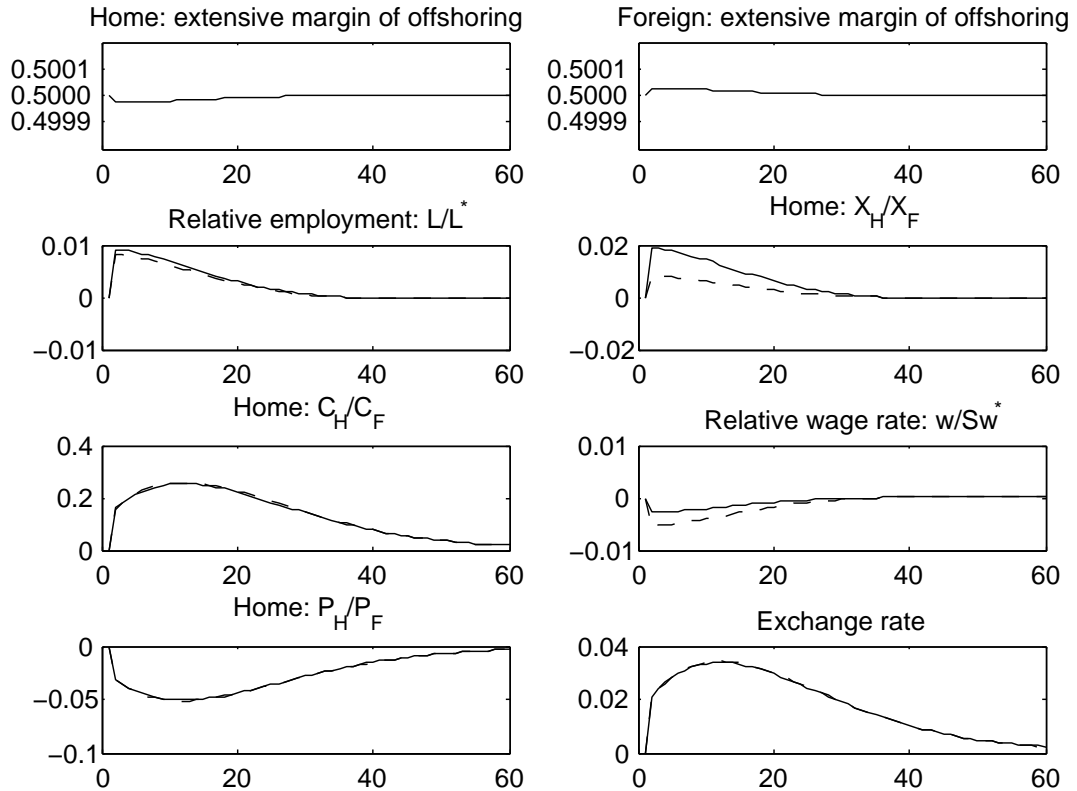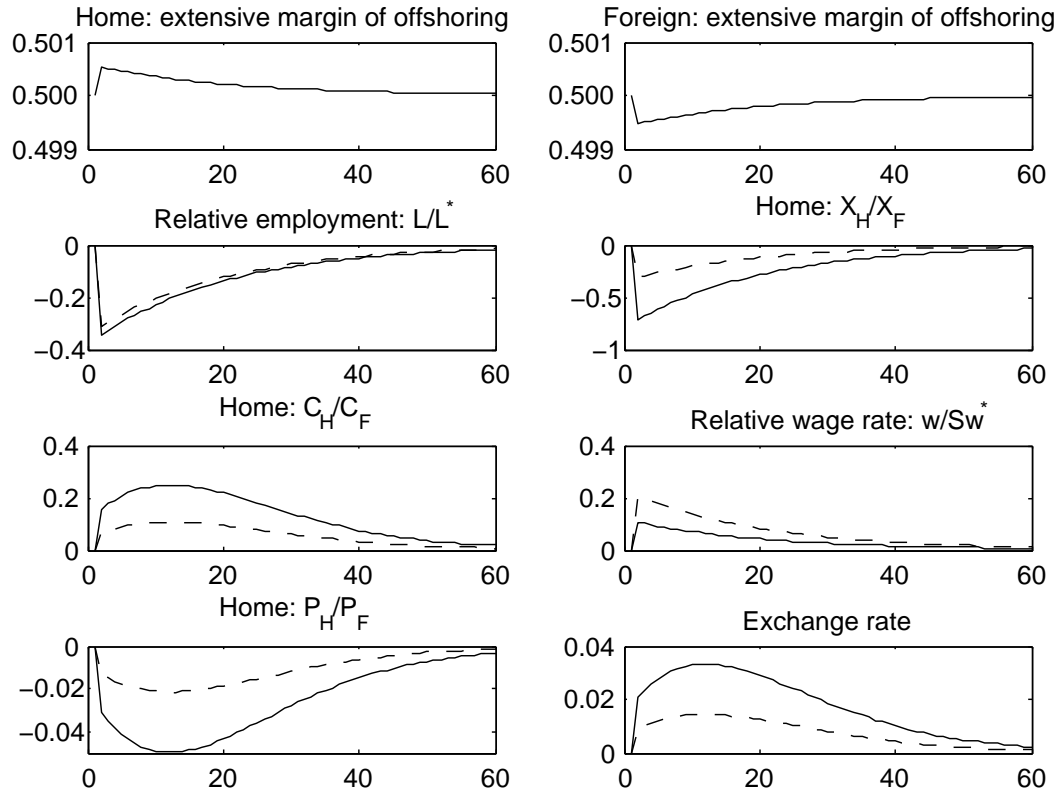
Figure 4.11 Impulse responses to a labor supply shock in the home country (Z_L). The response of the extensive margin of offshoring, I, is in levels. All other impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.
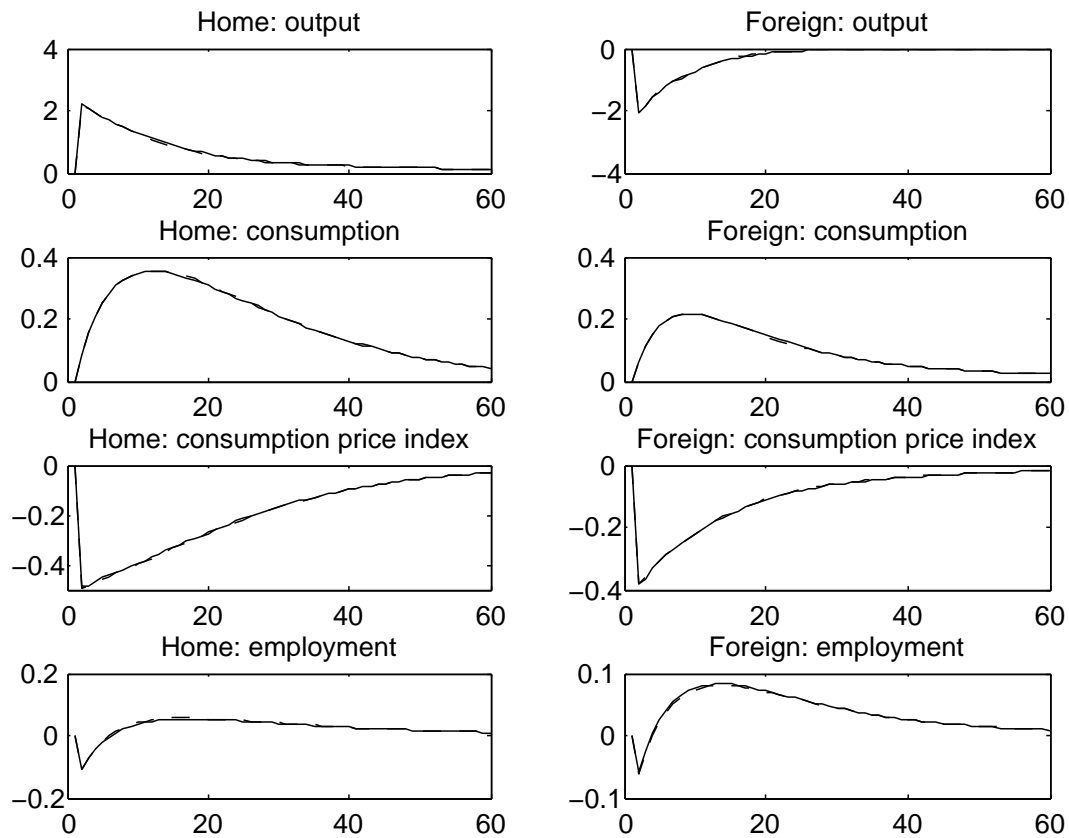
Figure 4.12 Impulse responses to a productivity shock in the home country (Z_A) with low ψ. All impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.
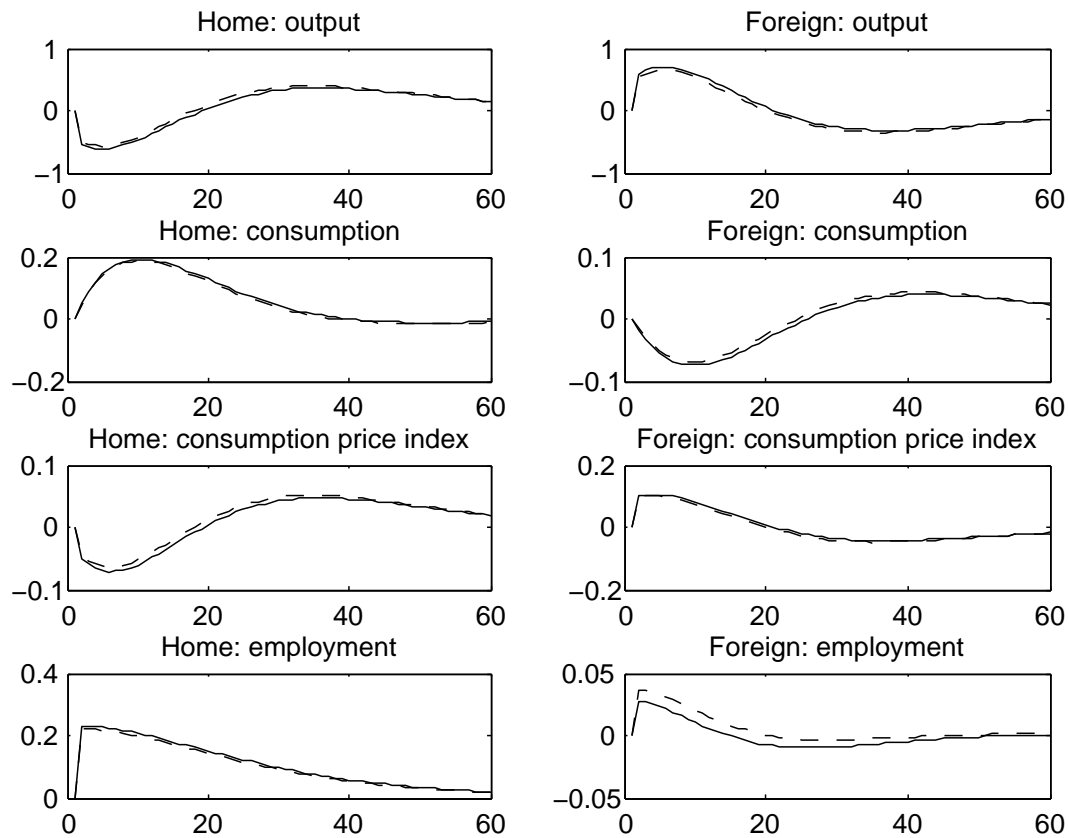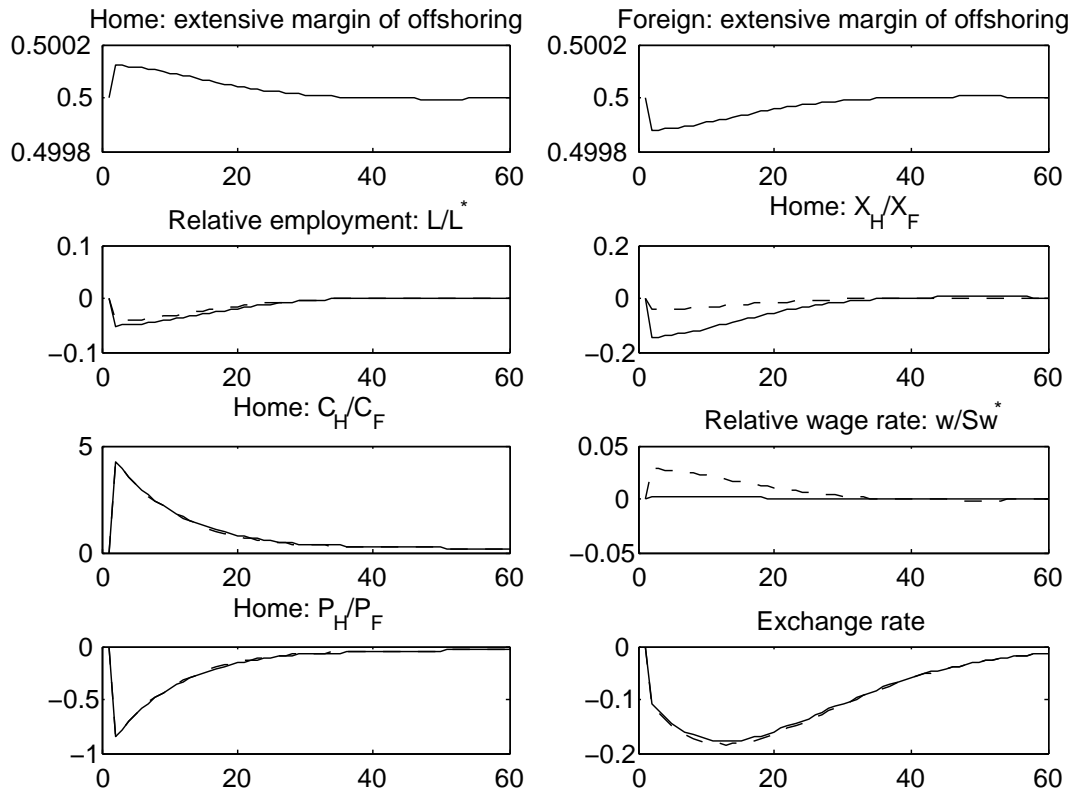
Figure 4.13 Impulse responses to a productivity shock in the home country (Z_A) with low ψ. The response of the extensive margin of offshoring, I, is in levels. All other impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.
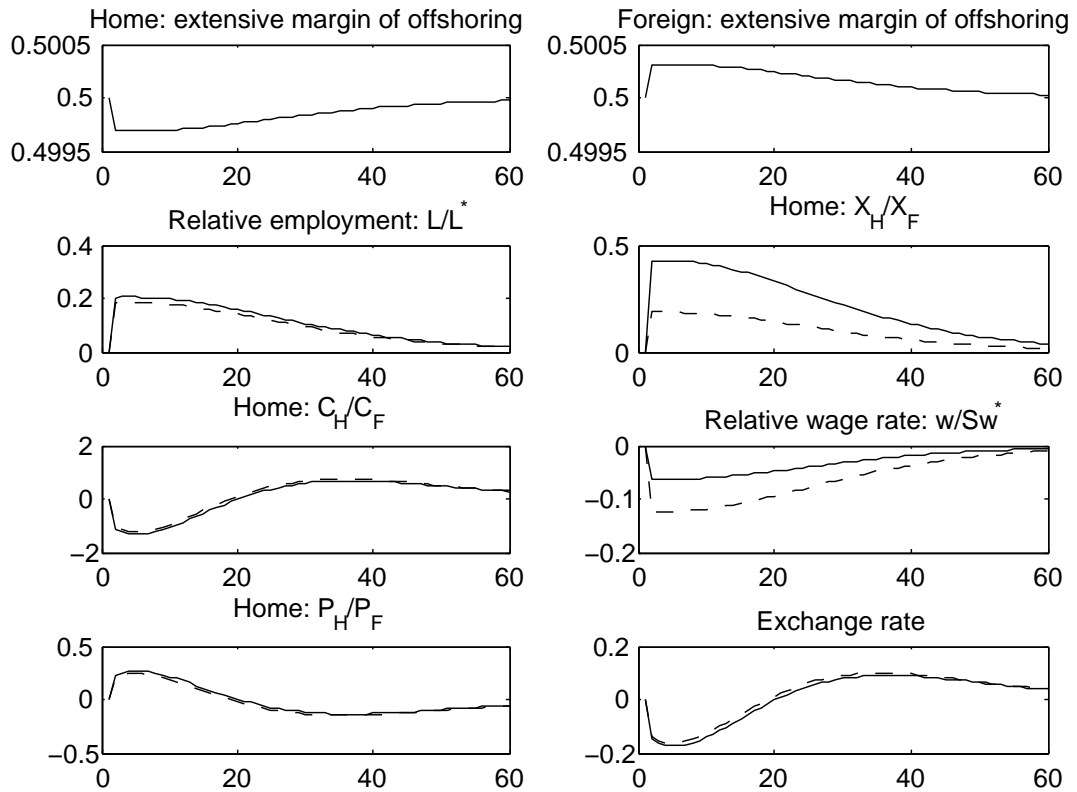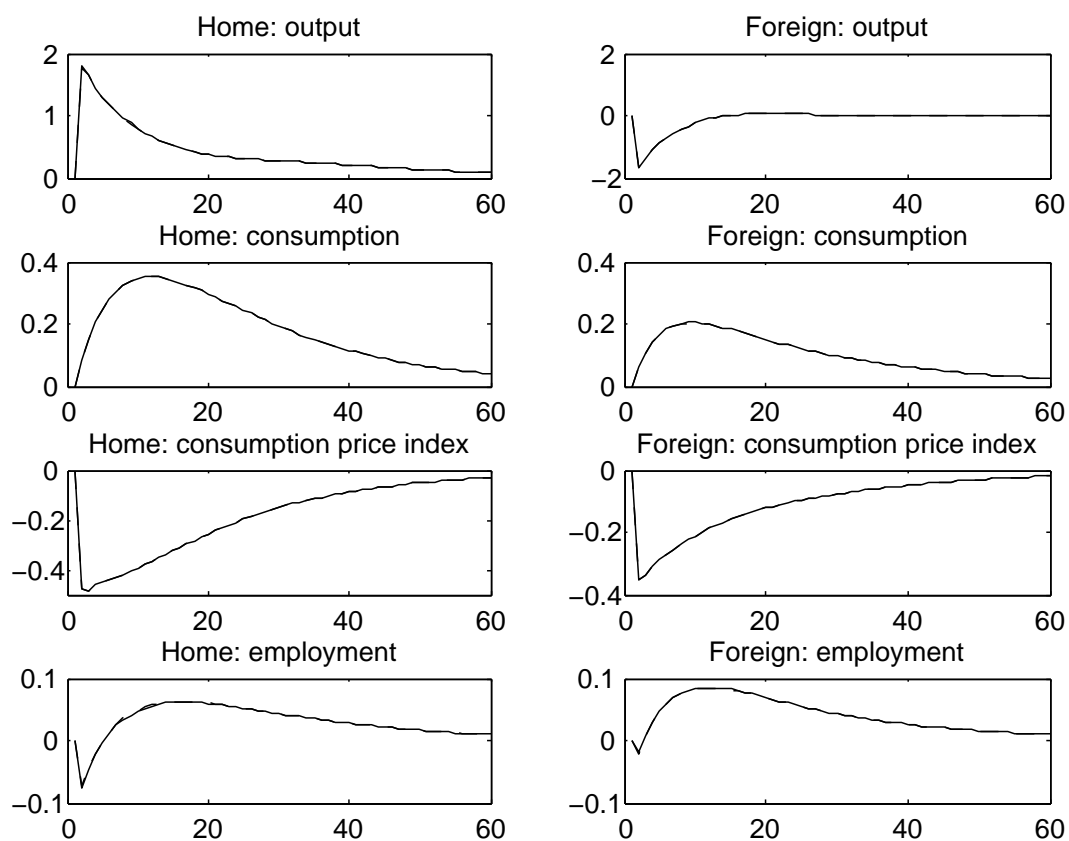
Figure 4.14 Impulse responses to a productivity shock in the home country (Z_A) with high λ. All impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.
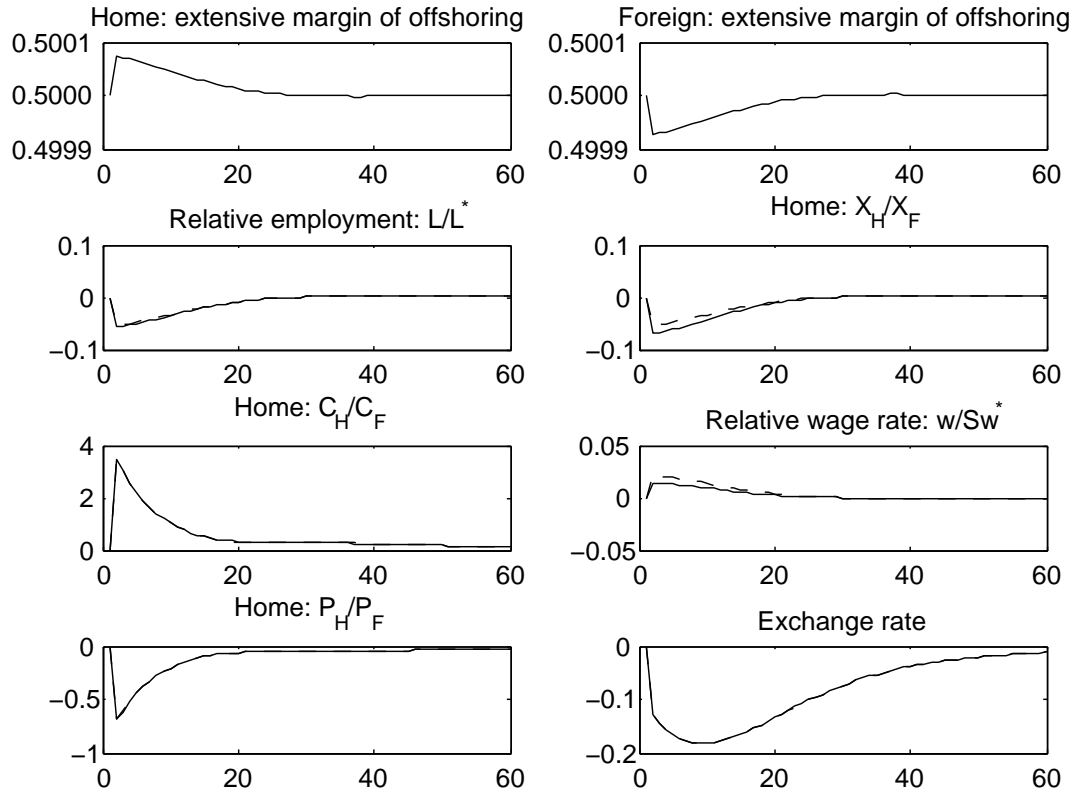
Figure 4.15 Impulse responses to a productivity shock in the home country (Z_A) with high λ. The response of the extensive margin of offshoring, I, is in levels. All other impulse responses show the percentage deviation from the initial steady state. Solid lines refer to the model with endogenous extensive margin of offshoring, while dashed lines correspond to the impulses with exogenous I.

Chapter 5

International linkages and business cycle synchronization[‡]

5.1 Introduction

The financial crisis that started in the United States in 2007 led to a severe downturn in many advanced and emerging economies. It is widely held that the remarkable cross-country synchronization of the downturn was promoted by the real and financial linkages established over decades of brisk economic integration. World trade had expanded significantly faster than world GDP over the years leading up the crisis (see Figure 5.1). In parallel, financial integration had progressed even more rapidly, as illustrated by surging international asset holdings (see Figure 5.2). Hence, at the eve of the financial crisis, the global economy was covered by a fine-meshed grid of trade and financial linkages, which allowed for the rapid transmission of macroeconomic shocks across the globe.

However, while the overall level of economic integration has clearly trended upward worldwide, integration has not progressed uniformly across countries and regions. In particular, countries in close geographical (or cultural) proximity continue to be more closely integrated with each other.[1] In addition, cross-country differences in sectoral specialization persist, counteracting the synchronization of national business cycles. Not surprisingly, therefore, there remains a significant variation in bilateral output correlations across country pairs. For instance, the

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[‡]This chapter is based on joint work with Stéphane Dées, published as an ECB Working Paper and as an article in the Open Economies Review: Dées and Zorell (2011) and Dées and Zorell (2012).

[1]This is in line with gravity models in the spirit of Tinbergen (1962). Gravity variables are found to be a good predictor not only for bilateral trade linkages (e.g. Anderson 1979, Anderson and van Wincoop 2003), but also for cross-border equity flows (e.g. Portes and Rey 2005) and FDI (e.g. Kleinert and Toubal 2010).
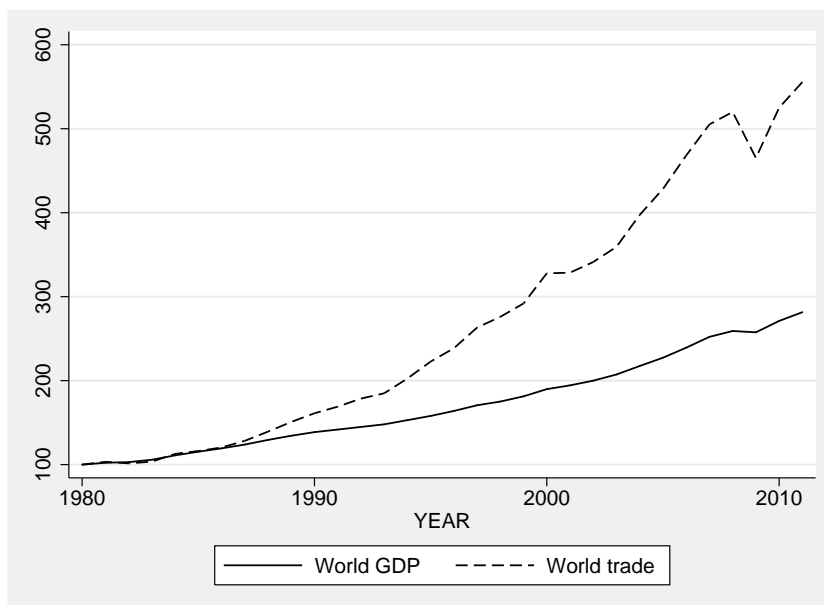
Figure 5.1 World trade and world GDP (constant prices). Indices, 1980=100. Source: IMF (World Economic Outlook database).

output correlation between France and Spain over the period 1993-2007 was as high as 0.93 (based on HP-filtered annual GDP data), whereas Portugal and New Zealand exhibited a correlation of -0.76.

Against this backdrop, this chapter explores empirically the determinants of international output co-movement in a cross section of 56 advanced and emerging economies. Drawing on the work by Imbs (2004, 2006), I estimate a system of equations which links, for each country pair, trade integration, financial integration, and the sectoral structure of production to the international synchronization of business cycles. The setting captures both direct and indirect effects of economic integration on output co-movement, which allows me to disentangle the role of the various channels and study the complex interaction of the various driving forces.

The chapter adds to the existing literature in that it provides a comprehensive assessment of how different types of financial linkages affect business cycle co-movement. More specifically, I look at the role of FDI as well as portfolio investment and its sub-components (equity and debt securities). This allows me to explore whether the various forms of financial integration have different effects on business cycle synchronization. To the best of my knowledge, this is the first attempt to explore the role of FDI linkages in a simultaneous equations framework modeling the drivers of business cycle synchronization.[2] Taking FDI linkages into

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[2]Hsu, Wu and Yau (2011) also look at the relationship between FDI linkages and output
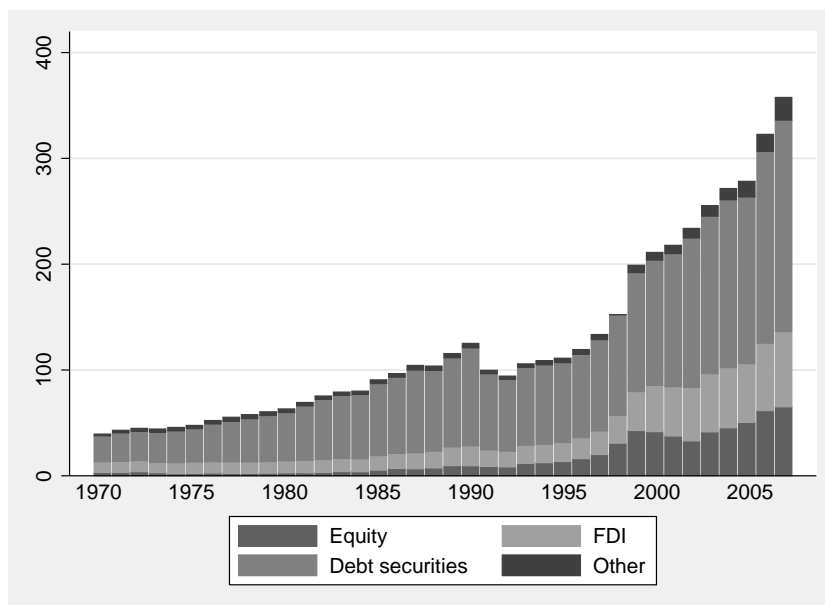
Figure 5.2 International financial asset holdings (global assets plus liabilities as a percentage of world GDP). "Debt securities" covers portfolio debt securities and other investment, such as bank loans. Source: Updated and extended version of data set constructed by Lane and Milesi-Ferretti (2007).

account is important for at least two reasons. First, although the bulk of international asset holdings continues to be related to portfolio investment (particularly debt securities), many countries witnessed a significant increase in the stock of inward and outward FDI holdings over the past decades (see Figure 5.3). The prevalence of FDI can even be seen as one of the characteristics setting the most recent wave of globalization apart from previous ones (Bordo et al. 1999). Second, the impacts of FDI on business cycle synchronization could differ from those of other financial linkages. Prima facie, stronger FDI linkages could have either a positive or a negative effect on output co-movement. On the one hand, large bilateral FDI holdings could mean that a technology shock in the home country is directly transmitted to the host country, because the parent companies may provide for rapid technology spillovers (Jansen and Stokman 2004). Parent companies suffering from a recession in the home country might also be forced to cut back employment and production abroad. To the extent that FDI is of a hori-

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co-movement in a simultaneous equations framework, based on panel data. It should be noted, however, that the paper was published after the publication of the working paper underlying this chapter (Dées and Zorell 2011) and was brought to my knowledge only recently. The paper only considers FDI linkages and ignores other forms of financial integration.

zontal nature, it could also lead to an assimilation of production structures and thereby foster output co-movement. For vertical FDI, the terms of trade effect described in Chapter 3 (and by Kose and Yi 2001, 2006) is another possible reason for closer output co-movement. On the other hand, one can also think of a negative effect of FDI linkages on business cycle synchronization. For instance, foreign subsidiaries might facilitate the rapid transfer of capital and production effort if the host country enjoys an idiosyncratic productivity shock, similar to the resource shifting mechanism envisaged by Backus et al. (1992).

(a) Assets   (b) Liabilities
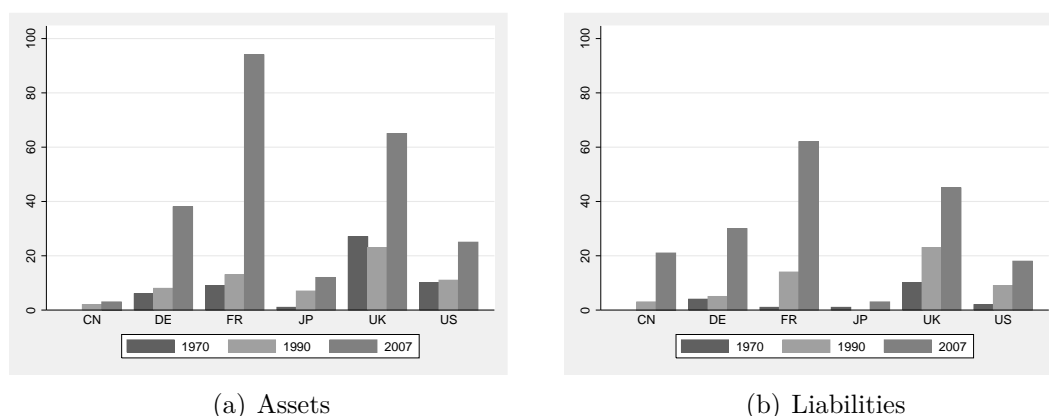
Figure 5.3 FDI stocks of five major economies over time (percentages of GDP). Source: Updated and extended version of data set constructed by Lane and Milesi-Ferretti (2007).

Overall, the results of the following empirical analysis confirm that economic integration fosters business cycle synchronization. Above all, the GDPs of economies with more intensive bilateral trade move more closely together. Similarity in production structure also leads to closer business cycle co-movement, which may point to the presence of common (industry-specific) shocks. By contrast, there is no evidence of a *direct* relationship between bilateral financial linkages and output correlation. In this respect, the results are located between existing papers finding a positive direct effect (e.g. Imbs 2004, 2006, Kose, Prasad and Terrones 2003*b*) and those pointing to a negative relationship between financial linkages and output correlations (e.g. García-Herrero and Ruiz 2008, Kalemli-Ozcan, Papaioannou and Peydró 2009). Notwithstanding this, I find that financial integration increases business cycle synchronization *indirectly* in that it fosters the assimilation of the sectoral structure of production. The indirect effects are large enough to more than offset the direct effect, so that the overall effect of financial integration on output co-movement becomes positive.

Crucially, the main findings hold true regardless of whether financial integration is measured in terms of FDI or portfolio holdings. This implies that, taking into

account indirect effects, cross-country FDI linkages go hand in hand with closer output synchronization. While the relationship was ambiguous ex ante, in the data the mechanisms giving rise to a positive relationship between FDI and output correlation (such as faster technology spillovers or Kose and Yi's terms of trade effect) appear to dominate the others.[3] It is also noteworthy that the main results from the full sample (which includes 56 advanced and emerging economies) are fairly similar to those from the sub-samples covering only OECD and EU countries, respectively. Interestingly, though, the direct link between financial integration and output correlation becomes positive and significant when the sample is restricted to EU countries. The estimated direct impact of financial integration on output co-movement also becomes positive and significant when the instruments for financial integration used in the baseline regressions (indicators of de iure restrictions on cross-border capital flows provided by Schindler 2009) are replaced by the same set of instruments used by Imbs (2004, 2006).[4] Both sets appear to be relevant instruments, according to standard diagnostic tests. I therefore conclude that the positive direct effect of financial integration highlighted by Imbs (2004, 2006) is not as robust as the other results. This point clearly deserves special attention in future research.

The remainder of this chapter is structured as follows. The next section briefly reviews the related theoretical and empirical literature. The empirical methodology is described in Section 5.3, while Section 5.4 discusses the results. Section 5.5 concludes.

5.2   Literature review

Explaining international output co-movement is challenging. Empirically, the international correlation of output varies significantly across country pairs, but tends to be positive (e.g. Ambler, Cardia and Zimmermann 2004, Backus et al. 1992). There is also some evidence of a secular increase in international business cycle synchronization among industrialized countries over the 20th century (Bordo and Helbling 2011).[5] Furthermore, the observed cross-country correlation is generally larger for output than for consumption or productivity. In a seminal paper, Backus et al. (1992) showed that this is at odds with the predictions of a basic two-country, one-sector RBC model, where agents have access to complete markets for state-contingent claims and can trade goods costlessly between countries. In such a

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[3]Hsu et al. (2011) come to similar conclusions.

[4]Imbs (2004, 2006) makes use of institutional variables from La Porta, Lopez-de-Silanes, Shleifer and Vishny (1998).

[5]For contrasting evidence on the co-movement between the United States and the rest of the world, see Heathcote and Perri (2004).

model, agents respond to an idiosyncratic TFP shock by shifting capital into the country experiencing the temporary boom. This results in low, or even negative international output correlation. At the same time, the cross-country consumption correlation is significantly higher, because agents in both countries seek to smooth consumption over time. The discrepancy between the model results and the data was dubbed the "quantity anomaly" by Backus et al. (1992). The BKK paper spawned an extensive theoretical literature on international output co-movement, which has identified a number of factors that can bring the model results closer to the data. For instance, there are papers modifying the standard IRBC model to include incomplete asset markets (e.g. Baxter and Crucini 1995, Kehoe and Perri 2002, Kouparitsas 1996), non-traded goods (e.g. Stockman and Tesar 1995), multiple sectors (e.g. Ambler et al. 2002), or vertical linkages (e.g. Burstein et al. 2008, Huang and Liu 2004, Kose and Yi 2001, 2006).

While the theoretical literature has come closer to replicating the observed cross-country output correlation and its ranking compared with the cross-country correlations of other macro variables (particularly consumption), a consensus on the most relevant drivers of business cycle synchronization has not emerged yet. A first strand of the literature emphasizes the role of common shocks to explain output co-movement. For instance, Bordo and Helbling (2011) argue that common shocks are the dominant driver of the secular increase in business cycle synchronization observed among the industrialized economies over the past century. Using a structural VAR approach, Stock and Watson (2005) also find that common shocks play an important role in explaining the changes in output co-movement among the G7 countries (although they find evidence of lower output synchronization over the most recent decades). Kose, Otrok and Whiteman (2003) and Crucini, Kose and Otrok (2011) document the importance of common factors driving business cycles, particularly in developed economies, on the basis of dynamic factor models.

The second school of thought, which is closer to this chapter, focuses on the role of international transmission channels. Starting with trade linkages, theoretical models do not provide definitive guidance on whether they have a positive impact on output co-movement or not. If trade fosters specialization (according to comparative advantages) and industry-specific shocks are important, closer trade linkages could result in more idiosyncratic business cycles. By contrast, if higher trade linkages increase intra-industry trade (also in parts and components), then stronger trade ties might lead to higher business cycle synchronization (see, for instance, Kose and Yi 2001). Despite the theoretical ambiguity, a vast body of empirical studies documents that countries with closer trade linkages exhibit higher output co-movement (e.g. Clark and van Wincoop 2001, Frankel and Rose 1998, Imbs 2004, 2006, Kose, Prasad and Terrones 2003*b*, Kose and Yi 2006). Recent papers looking specifically at the role of vertical linkages also find a positive

link with business cycle synchronization (e.g. di Giovanni and Levchenko 2010, Ng 2010).

Turning to the role of financial integration, the picture is less clear-cut.[6] For instance, Kouparitsas (1996) shows in an IRBC framework that financial integration lowers output synchronization if asset markets are complete, whereas it increases output co-movement if agents only have access to a non-contingent bond. Heathcote and Perri (2004) find that financial integration responds endogenously to less correlated real shocks and diminishes output co-movement. Empirically, Imbs (2004, 2006) finds evidence of a positive direct impact of financial integration on business cycle synchronization. Kose, Prasad and Terrones (2003b) come to similar conclusions. By contrast, Kalemli-Ozcan, Sorensen and Yosha (2003) reckon that financial integration leads to higher specialization of production and, thereby, lowers output co-movement. The intuition is that international trade in financial assets allows countries to insure against idiosyncratic risk, which enables them to exploit their comparative advantages.[7] Using a rich panel dataset on banks' international exposure, Kalemli-Ozcan et al. (2009) also find a negative relationship between financial integration and business cycle synchronization. The panel data allow to control for time-invariant country-pair factors and global trends affecting both financial integration and business cycle patterns. While most of the existing empirical studies focus on financial linkages in the form of portfolio investment or "other investment" (including bank loans), a handful of papers also look at FDI linkages. Based on a single-equation framework, Jansen and Stokman (2004) find that economies with closer FDI linkages exhibit higher business cycle synchronization. Hsu et al. (2011) arrive at similar conclusions.

The work by Imbs (2004, 2006), on which this chapter is based, can be seen as a synthesis of the two competing strands of the literature. On the one hand, Imbs emphasizes the role of international integration in explaining output co-movement. He finds that both trade and financial linkages are conducive to synchronization. On the other hand, he also takes the cross-country similarity of the sectoral structure of production into account. The latter partially picks up the role of common shocks, since countries with similar industries are more likely to face similar shocks, as highlighted by the literature on optimal currency areas. The similarity of production is found to be an important explanatory factor for international output co-movement. In contrast to other papers, Imbs estimates a system of simultaneous equations linking output correlation, trade, financial linkages, and the similarity

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[6]There is also an extensive literature on the role of financial integration on output volatility. See, for instance, Buch (2002), Buch, Döpke and Pierdzioch (2004, 2005).

[7]However, financial integration between two economies could also increase the similarity of their production structures, as foreign investment could be concentrated on similar activities, for instance those dependent on external funds (Imbs 2006, Rajan and Zingales 1998).

in production rather than relying on a single-equation framework.[8] Thereby, Imbs takes into account not only the direct effects of international linkages on output co-movement, but also indirect effects working through the interaction of the various determinants.

5.3   Methodology

5.3.1   Framework

Following Imbs (2004, 2006), I estimate a system of four equations relating bilateral output correlations with measures of trade and financial integration as well as the similarity in the sectoral production structure. Each observation corresponds to a country pair (i, j):

$$\rho_{i,j} = \alpha_0 + \alpha_1 T_{i,j} + \alpha_2 F_{i,j} + \alpha_3 S_{i,j} + \alpha_4 I_{1,i,j} + \varepsilon_{1,i,j} \tag{5.1}$$

$$T_{i,j} = \beta_0 + \beta_1 F_{i,j} + \beta_2 S_{i,j} + \beta_3 I_{2,i,j} + \varepsilon_{2,i,j} \tag{5.2}$$

$$S_{i,j} = \gamma_0 + \gamma_1 T_{i,j} + \gamma_2 F_{i,j} + \gamma_3 I_{3,i,j} + \varepsilon_{4,i,j} \tag{5.3}$$

$$F_{i,j} = \delta_0 + \delta_1 I_{4,i,j} + \varepsilon_{3,i,j} \tag{5.4}$$

Here, the four endogenous variables are the bilateral output correlation ρ, the bilateral trade intensity T, an index S capturing the similarity between countries i and j, and the intensity of financial links between these two countries, denoted F. I_1, I_2, I_3 and I_4 denote exogenous variables.

Equation (5.1) is rather standard in the literature studying the empirical determinants of cross-country GDP correlation in the vein of Frankel and Rose (1998) and relates bilateral output correlations to measures of trade and financial integration as well as the similarity in production patterns. Equations (5.2) to (5.4) capture the interaction of the endogenous explanatory variables, which makes it possible to disentangle direct from indirect channels. The specification of these equations leans on Imbs (2004, 2006).[9] Figure 5.4 gives an overview of the estimation framework and shows the various channels through which economic and financial integration affect cross-country output correlations.

Equations (5.1)-(5.4) form a system of simultaneous equations. This means that some of the regressors will be correlated with the error terms and that Ordinary Least Squares (OLS) estimates will be biased. To overcome simultaneity bias, I follow Imbs (2004) in estimating the system using the Three-Stage Least Squares (3SLS) estimator going back to Zellner and Theil (1962). 3SLS is essentially a combination of a Seemingly Unrelated Regression (SUR) and Two-Stage

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[8]Abbott, Easaw and Xing (2008) and García-Herrero and Ruiz (2008) use a similar approach.

[9]Imbs (2004) estimates a similar system with $\beta_1 = 0$, while Imbs (2006) imposes $\beta_2 = \gamma_1 = 0$ and includes T as a dependent variable in equation (5.4).
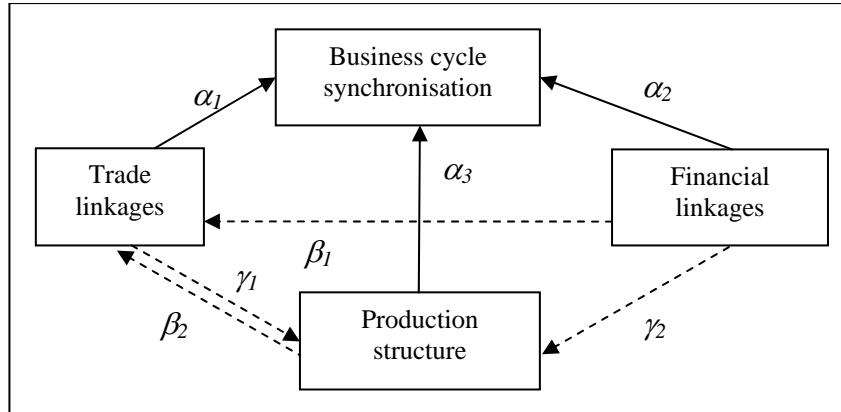
Figure 5.4 Estimation framework

Least Squares (2SLS). Unlike 2SLS, however, 3SLS is a full information estimator that takes the covariance structure between the error terms into account. 3SLS is therefore not only consistent but generally also asymptotically more efficient than 2SLS in this context (e.g. Hausman 1984). The drawback of this estimator is that it is more vulnerable to misspecification. All coefficients in all equations would be inconsistently estimated if one of the equations were misspecified. Therefore, I will also consider alternative estimation methods.

5.3.2 Data

As in Imbs (2006), the dependent variable, $\rho_{i,j}$, is the pairwise correlation of HP-filtered GDPs, computed over the period 1993-2007. The GDP data are taken from the IMF's International Financial Statistics (IFS). (See also the data overview in Section 5.6.2 in the appendix.) Table 5.1 shows that the baseline measure of business cycle synchronization, which is based on HP-filtered annual time series, is highly correlated with measures based on alternative filtering techniques.[10]

Bilateral trade linkages are captured by an indicator proposed by Deardorff (1998), which corrects for the size (or "mass") of the two trading partners:

$$T_{i,j} = \frac{1}{T} \sum_t \frac{(EX_{ij,t} + IM_{ij,t})\, NYW_t}{NY_{i,t} NY_{j,t}}. \tag{5.5}$$

Here, $EX_{ij,t}$ and $IM_{ij,t}$ denote total merchandize exports and imports, respectively, from country i to country j. Furthermore, NYW_t stands for world nominal output, while $NY_{i,t}$ and $NY_{j,t}$ denote the nominal GDP in countries i and j, respectively.

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[10]The estimation results based on these alternative filtering methods are not reported here, but are very similar to those presented below and consistent with the main conclusions.

Turning to financial market integration, existing studies in this branch of the literature focus on portfolio investment. This chapter goes beyond the existing literature in that it also uses FDI-related linkages as an alternative measure of financial integration. Bilateral FDI linkages - as reported by the OECD's Foreign Direct Investment Statistics - are measured as the sum of country i's FDI position in country j and j's FDI position in i:

$$F_{i,j} = \frac{1}{T} \sum_t \left(F_{ij,t} + F_{ji,t} \right).$$ (5.6)

Since most countries report inward as well as outward FDI holdings, it is possible to expand the sample beyond the pairs formed by the 30 reporting OECD economies. Analogously, portfolio investment linkages are measured as the sum of bilateral portfolio investment positions (taken from the IMF-CPIS database). I also look at the decomposition of portfolio linkages into two broad sub-categories, namely equity and debt securities. For all categories of financial linkages, I also compute alternative measures correcting for country size. They are defined analogously to the trade indicator in equation (5.5):

$$\widetilde{F}_{i,j} = \frac{1}{T} \sum_t \frac{\left(F_{ij,t} + F_{ji,t} \right) NYW_t}{NY_{i,t} NY_{j,t}}.$$ (5.7)

Similarities in the production structure are measured as follows:

$$S_{i,j} = \frac{1}{T} \sum_t \sum_n^N \left| s_{n,i,t} - s_{n,j,t} \right|.$$ (5.8)

Here, $s_{n,i}$ $(s_{n,j})$ is sector n's share in total value added in country i (j). The total number of sectors is N. If i and j are completely symmetric, then $S_{ij} = 0$. Hence an increase in S is tantamount to greater specialization. I use UNIDO data on gross value added for six broad sectors.[11]

I now turn to the description of the exogenous variables and instruments. To start with, I_2 comprises standard gravity variables: the bilateral distance between the countries' capitals and two dummy variables indicating, respectively, if the countries share a common border and if they used to be part of a single jurisdiction.

In line with Imbs (2004), both the bilateral (log) product of, and the difference between GDPs per capita are included in I_4. This choice is motivated by Imbs and Wacziarg (2003) who find that specialization patterns depend on income per capita and that this relationship is non-monotonous. As countries become more

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[11]The six sectors are: Agriculture, hunting, forestry, fishing (ISIC A-B); mining, manufacturing, utilities (ISIC C-E); construction (ISIC F); wholesale, retail trade, restaurants and hotels (ISIC G-H); transport, storage and communication (ISIC I); other Activities (ISIC J-P).

affluent, they first diversify their production, only to specialize again when they pass a certain threshold.

The baseline regressions also involve the use of instruments for financial integration. The financial instruments are taken from the panel data set by Schindler (2009), which contains various summary measures of de iure restrictions on cross-border financial transactions for 91 countries. Like several others (e.g. Miniane 2004), Schindler (2009) draws on the IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER). For the purposes of this chapter, Schindler's data set has the advantage of providing information on cross-border financial restrictions separately for various asset categories. In addition, the country coverage is fairly broad, ranging from low-income to high-income countries. In the regressions, I make use of summary measures covering both inward and outward restrictions.[12] While the underlying AREAER series are binary dummy variables, Schindler's summary measures take on any value between zero and one. In the sensitivity analysis, I will also make use of an alternative set of instruments for financial linkages constructed by La Porta et al. (1998). This data set comprises several measures of legal institutions in finance: shareholder rights (with variables showing whether one share carries one vote, whether the distribution of dividends is mandatory, whether proxy vote by mail is allowed, and the percentage of capital necessary to call an extraordinary shareholders' meeting), creditor rights, and an assessment of accounting standards and the rule of law. This set of instruments has the advantage of allowing for a direct comparison with the estimates by Imbs (2004, 2006). The drawback is that the variables do not so much relate to cross-border financial transactions, but rather to the local legal framework in finance in general.

All in all, the full sample comprises 56 countries (see Section 5.6.3 in the appendix). Taking into account missing observations, one arrives at a maximum of 964 country pairs for the whole sample. By comparison, Imbs (2004) only considered 24 countries and Imbs (2006) included 41 countries in the sample. Two sub-samples - covering only OECD and EU countries, respectively - are also considered to check the robustness of the results obtained with the full sample.

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[12] The summary measure is the arithmetic average of inward and outward restrictions. I also experimented with a measure that always picks the more severe restriction (i.e. either the inward or the outward restriction), without changes to the main results.

5.4   Empirical results

5.4.1   Descriptive statistics

Before delving into the econometric analysis, this section presents a few descriptive statistics. Table 5.2 reports summary statistics for the most important variable, i.e. output correlation. The cross-sectional variation in bilateral output correlation coefficients is large, but fairly similar for the various (sub-)samples considered. The average output correlation is around 0.3 in all samples. Some of the highest correlations are observed for EU country pairs, such as France and Spain (0.93) or Belgium and Germany (0.88).

Table 5.3 presents the unconditional correlations of the endogenous variables. A few interesting results emerge. First, for the full sample, the correlation with the output co-movement variable (ρ) is lowest for trade integration (8 percent) and much higher for the similarity in production structure (20 percent) and financial integration (between 20 and 30 percent). While the correlation between ρ and S remains broadly unchanged whatever sample considered, the correlations between ρ and T and between ρ and F are highest when the pairs are restricted to OECD countries. Second, the correlation between trade and financial integration is overall rather low. However, when considering FDI-based relationships, this correlation increases somewhat (standing between 10 and 20 percent). Third, there is a rather high correlation between the similarity index S and financial integration F (between 30 and 45 percent), especially when F is measured by portfolio investment. Finally, the correlation across the various measures of financial integration is very high. However, while this correlation is close to 90 percent between equity investment and debt holdings, it is somewhat lower between portfolio and FDI-based measures, justifying the approach to estimate the system with alternative measures of financial integration.

Overall, while this simple correlation-based analysis anticipates some of the estimation-based results, it shows above all the complexity of the interconnections across the various channels that are at play in the international transmission of shocks. It also calls for an empirical analysis based on a system of simultaneous equations, as detailed above, given the potential for high and significant indirect effects between output correlations and its various determinants.

5.4.2   Estimation results

In the following, I will estimate the system described in Section 5.3. In doing so, I will consider several alternative measures of financial integration (FDI as well as portfolio investment and its sub-components) and samples with different country coverage (full sample, OECD economies and EU Member States). Since

the main results are obtained by instrumenting financial integration by a new set of indicators, the robustness of the results is tested by using an alternative set of instruments - based on La Porta et al. (1998) - that is widely used in the literature.

Table 5.4 gives the 3SLS estimates of equations (5.1)-(5.4) for the period 1993-2007 and reports estimates with financial integration measured by various asset categories (FDI as well as portfolio investment and its sub-categories). Estimations reported in Table 5.5 restrict the sample to OECD pairs, while Table 5.6 presents the results for pairs of EU Member States.

Among the determinants of output correlations, trade integration and the similarity in production structure are significant with the expected signs (equation (5.1)). To be more specific, trade integration tends to foster business cycle synchronization. This is in line with a vast body of literature (e.g. Clark and van Wincoop 2001, Frankel and Rose 1998, Kose and Yi 2001). The value of the coefficient α_1 is higher when restricting the sample to OECD or EU pairs. However, this coefficient is found to be insignificant for EU pairs when F is measured by FDI or equity investment. This result may come as a surprise. In fact, in a similar exercise, Abbott et al. (2008) identify a positive and significant relationship between trade intensity and business cycle correlation for 16 European countries (when looking at the individual-country results). However, one should keep in mind that the EU Member States share relatively strong bilateral trade linkages. Restricting the sample to these countries thus reduces not only the sample size, but also the variance in the trade variable, diminishing the precision with which the coefficient α_1 is estimated.

Furthermore, the coefficient associated with similarities in sectoral structure is in most cases negative, i.e. the more similar two countries are (low S), the higher is the correlation of their outputs. The coefficient is slightly lower when the sample includes only OECD or EU economies. This effect is in line with Imbs (2006). The intuition is that countries with similar sectoral characteristics are more likely to be hit by similar (sector-specific) shocks. Hence the results are indicative of an important role of common shocks in driving business cycle synchronization.

In contrast to Imbs (2004, 2006), there is no evidence of a positive, significant relationship between bilateral financial linkages and business cycle correlation. α_2 is positive and significant only in two cases: when F is measured using debt holdings and when the sample is restricted to EU country pairs. This important finding will be discussed in greater detail below.

Concerning the indirect effects working through trade (equation (5.2)), the impact of financial integration on trade is negative, as shown by the estimates of β_1. Thus, closer financial integration is associated with lower bilateral trade linkages. While Imbs (2006) had difficulties finding significant effects of finance on trade, the coefficients here are significant and negative regardless of the measure of finan-

cial linkages used. The interpretation of this result is particularly straightforward when financial linkages are measured by FDI. In this case, trade and financial integration can be seen as substitutes. After all, FDI continues to be dominated by horizontal rather than vertical investment, despite the increasing role of vertical linkages (e.g. Markusen 1995). From the perspective of an individual firm, horizontal FDI is an alternative strategy to exporting (Helpman, Melitz and Yeaple 2004), providing direct access to the host country and, possibly, neighboring markets. This interpretation is also consistent with the fact that the absolute value of β_1 is higher when restricting the sample to EU countries. In fact, direct investment among advanced economies, such as the EU member states, tends to be more of a horizontal nature. (In the OECD sample, β_1 has the same sign, but is not significant.) Furthermore, similarity in production structures stimulates trade ($\beta_2 < 0$), especially when F is measured by portfolio investment.

Finally, the indirect channels operating through structural similarity (equation (5.4)) appear relevant. Trade linkages between two countries reduce the similarity in their structure of production ($\gamma_1 > 0$). This could reflect the fact that (inter-industry) trade allows countries to specialize on specific industries according to comparative advantages. Interestingly, the corresponding coefficient is highest when F is measured by FDI. However, the effect is not significant when restricting the sample to EU country pairs.

Concerning the effects of financial integration on structural similarity, the sign of γ_2 is a priori ambivalent, as pointed out by Imbs (2006). Financial integration could either favor specialization in different sectors or rather foster the concentration of activities in certain sectors, e.g. those dependent on foreign capital. Unlike Kalemli-Ozcan, Sorensen and Yosha (2001) and Kalemli-Ozcan et al. (2003), I find that γ_2 is negative and significant, regardless of the sample considered. Hence closer financial linkages are associated with greater similarity in production. The effect is particularly strong for the OECD sample. Also, when F is measured by FDI, the value of γ_2 is - in absolute terms - higher than when it is measured by portfolio investment.

As a full information estimator, 3SLS is sensitive to misspecification. However, the main findings remain intact if the equations are estimated separately using either 2SLS or the Generalized Method of Moments (GMM). In particular, α_2 remains negative and insignificant (see Table 5.4). Furthermore, the 3SLS estimates of α_2 remain insignificant if one corrects the measure of financial linkages for the economic size of the country pairs (see the last column in Table 5.4).

Figure 5.5 summarizes the main results. Economies with tighter bilateral trade linkages tend to move more closely together. Also, similarity in the sectoral composition of production leads to closer business cycle co-movement. By contrast, there is no evidence of a direct effect of financial linkages on output correlation.

It is remarkable that the main results go through regardless of the measure of financial integration used. This suggests that FDI and portfolio investment have very similar effects on business cycle synchronization.

In a way, the insignificance of the direct effect of finance on output synchronization positions this chapter between papers finding a positive effect (e.g. Imbs 2004, 2006, Kose, Prasad and Terrones 2003a) and those pointing to a negative relationship (e.g. García-Herrero and Ruiz 2008, Kalemli-Ozcan et al. 2009). In principle, the discrepancy between these findings is not surprising, given that the theoretical predictions on the link between financial integration and business cycle co-movement are not clear-cut either (see Section 5.2). Anyway, the issue is of central importance and therefore merits further investigation. In a first step, I will therefore first explore whether the indirect effects of financial integration may compensate for the absence of a significant direct link (Section 5.4.3). In a second step, I will investigate whether the discrepancy between Imb's results and those presented here might reflect the use of different instruments for financial linkages (Section 5.4.4).
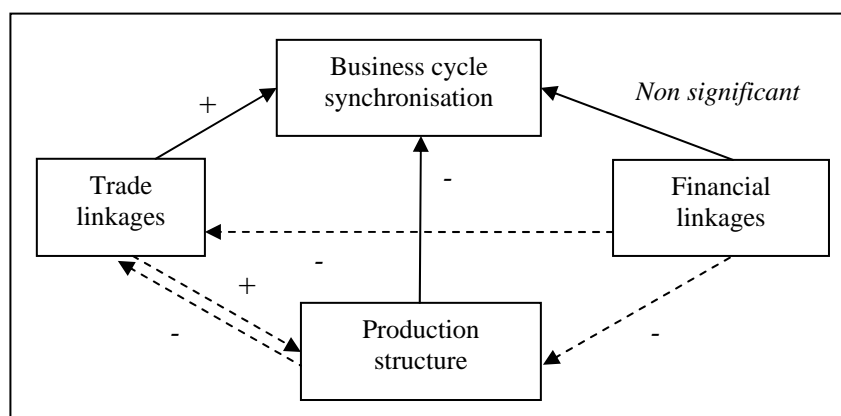
Figure 5.5 Summary of estimation results

5.4.3 Disentangling the importance of the different channels

The system of equations (5.1)-(5.4) allows for a complex interplay of direct and indirect channels affecting business cycle synchronization. Thus, the direct effects suggested by equation (5.1) could be offset by the indirect ones captured by the remaining equations. To derive the overall impacts of trade and financial integration as well as sectoral similarity, respectively, the direct and indirect effects are

combined, using the results from the simultaneous estimation.[13] Tables 5.8 and 5.9 report the values for the indirect channels together with the overall effects when F is measured by FDI and portfolio investment, respectively.

To start with, it turns out that the direct effect of trade on output correlations (α_1) is overall found to be positive and significant. Given the specification of the system, indirect trade effects can only stem from interactions with sectoral similarity, S. As already shown, trade integration tends to reduce the similarity in production structure. As this in turn reduces output correlation, the indirect effect of trade on business cycle synchronization ($\alpha_3\gamma_1$) tends to be negative, countervailing the direct impact. However, the overall effect ($\alpha_1 + \alpha_3\gamma_1$) remains positive and significant. It is highest in the OECD sub-sample and in the EU sub-sample, when F is measured by portfolio investment. Only in one case, using the whole sample and measuring F by FDI, do the indirect effects of trade cancel out the direct ones.

Turning to sectoral similarity S, the system allows only for indirect effects through trade integration. Since lower similarity tends to be associated with lower trade linkages, this may reinforce the direct effect. However, the indirect effects are found to be small and insignificant. Thus, the overall impact ($\alpha_3 + \alpha_1\beta_2$) is fairly close to the direct one, confirming that higher similarity in production structures leads to higher business cycle synchronization. The effect is largest when estimating the system on the full sample.

As already indicated, taking heed of indirect channels is particularly relevant for financial integration. While no positive, significant direct effects of financial linkages on output correlation have been found, the indirect effects are large enough to change the overall assessment. The first indirect effect stems from interactions with trade integration. Since financial integration tends to reduce bilateral trade (and trade fosters output correlation), this indirect effect could diminish the impact of financial linkages on business cycle correlation. However, as shown in Tables 5.8 and 5.9, this indirect effect is small and in most cases insignificant. The second indirect effect operates through sectoral similarity. The estimates show that financial integration between two countries makes them more similar in terms of sectoral production patterns. Sectoral similarity, in turn, tends to increase output correlation. Thus, the second indirect channel creates a positive link between financial integration and business cycle synchronization. The effect is large and significant, so that the overall financial channel is clearly positive and significant.

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[13]The overall effects of, say, T can be derived by using equations (5.3)-(5.4) to eliminate S and F from equation (5.1) and taking the derivative of ρ with respect to T. This yields $\alpha_1 + \alpha_3\gamma_1$. For similarity S, the overall effect is given by $\alpha_3 + \alpha_1\beta_2$. The overall effect of F is more complicated, since both S and T respond endogenously to changes in F: $\alpha_2 + \alpha_1\beta_1 + \alpha_3\gamma_2 + \alpha_1\beta_2\gamma_2 + \gamma_1(\beta_1 + \beta_2\gamma_2)/((\alpha_1\beta_2 + \alpha_3)(1 - \beta_2\gamma_1))$. That said, the last two summands, which capture the most roundabout effects, will turn out to be close to zero and can be ignored in a first approximation.

It is especially large for the sub-samples including only OECD or EU countries. In a nutshell, I find that financial linkages do not foster international business cycle synchronization directly, but rather indirectly, by increasing the similarity of the financially integrated economies. Such an indirect effect would go unnoticed in a single-equation framework, which underlines the advantages of the simultaneous equations approach chosen in this chapter.

5.4.4   Sensitivity to the financial integration instruments

The estimation strategy in this chapter involves the use of instruments for financial integration. The financial instruments in the benchmark estimations rely on measures of de iure restrictions on cross-border financial transactions, provided by Schindler (2009). By contrast, Imbs (2004, 2006) uses institutional variables from La Porta et al. (1998). Instrument diagnostics suggest that both sets - which have been described in Section 5.3.2 - are relevant instruments for financial integration.[14]

To check whether the choice of instruments for financial integration might influence the results, I re-estimate the system using - like Imbs - the set of institutional variables from La Porta et al. (1998). It turns out that, consistent with Imbs' findings, the direct effect of financial integration on ρ becomes positive for the OECD sample when using the variables from La Porta et al. (1998) (see Table 5.10). However, the choice of the instruments does not fully explain the differences between Imbs' results and the findings in this chapter, since the direct effect of financial integration remains insignificant for the whole sample.

In fact, the sampling also seems to matter. The sample used here - comprising between 756 and 964 pairs, depending on the specification - is broader than the one used by Imbs. Imbs (2004) works with 276 pairs and Imbs (2006) with a maximum of 347 pairs. Using a much broader sample, also in terms of income levels and stage of financial development, seems to influence the results. García-Herrero and Ruiz (2008) also obtain results that are different from Imbs' using a sample that includes many emerging economies (but only Spain as the counterpart). Overall, the findings are consistent with the notion that financial integration is more relevant for business cycle synchronization among the advanced economies. This interpretation is in line with Kose, Prasad and Terrones (2003b) who show that the positive effect of economic integration on output co-movement is largely confined to the industrialized countries.

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[14]In particular, looking at the first-stage results and applying the critical values developed by Stock and Yogo (2002) to the corresponding F-statistics, the null hypothesis that the financial instruments are weak is rejected at the 5 percent significance level in both cases. For more details on this test, see also Stock, Wright and Yogo (2002). Notwithstanding this, the first-stage fit is somewhat better for the broader set of instruments based on La Porta et al. (1998).

To summarize, the estimated direct effect of financial integration on business cycle synchronization seems to be more sensitive to the use of alternative samples and instruments than the other main results. This not only puts a new complexion on the results by Imbs (2004, 2006), but also deserves special attention in future research. There is also some tentative evidence that financial integration plays a more important role in synchronizing business cycles among the advanced economies compared with the mixed sample of advanced emerging economies.

5.5   Conclusion

Drawing on the work by Imbs (2004, 2006), the empirical analysis in this chapter has brought some evidence about the role of trade and financial linkages in international business cycle synchronization. The results confirm that trade linkages foster output co-movement. In addition, similar production structures are associated with closer business cycle co-movement, which is likely to reflect the role of common shocks. By contrast, there is no evidence of a direct relationship between bilateral financial linkages and output correlation. However, financial integration fosters business cycle synchronization indirectly by raising the similarity in production structures. The indirect effects are large enough to render the overall effect positive. Notwithstanding this, the analysis indicates that the estimated direct effects of financial integration are quite sensitive to the set of financial instruments used and the underlying sample. This issue deserves greater attention in future research. By contrast, the results are quite robust the use of alternative measures of financial integration. In particular, FDI and portfolio investment are found to have similar effects on output co-movement. Accounting for indirect effects, both forms of financial integration seem to be conducive to closer output co-movement.

At first sight, the absence of a *direct* link between financial integration and output co-movement appears to be at odds with the experience during the global financial crisis of 2007-09. At the time, the demise of Lehman Brothers sent shock waves through international financial markets and virtually the entire world economy into a tailspin. However, Rose and Spiegel (2009) find no evidence that ex-ante bilateral exposure can explain the differential impact of the global financial crisis in a large cross section of countries. Hence the crisis may have involved an element of pure contagion or a common global shock, to which countries were exposed more or less independently of their financial ties with the United States. In addition, it cannot be excluded that the measures of financial integration used in this chapter do not fully capture all relevant transmission channels. For instance, the initial shock may have been propagated across borders through the lending activities of internationally active banks. Buch (2004) finds evidence for this mechanism, looking at the activities of German banks in smaller EU countries.

Third-country effects might also have played a role in the crisis of 2007-09, but are hard to capture in a model looking at bilateral country linkages. Bringing together these additional drivers of international business cycle synchronization with those described in this chapter is a promising avenue for future research.

5.6   Appendix to Chapter 5

5.6.1   Tables

	BP	CF	DIFF	HP
BP	1.00			
CF	0.77	1.00		
DIFF	0.77	0.68	1.00	
HP	0.74	0.50	0.93	1.00

Table 5.1 Correlation of alternative output co-movement measures. For each country pair, the correlation of the cyclical GDP component is computed (annual frequency) using alternative filters. The table shows the correlation of these output co-movement measures. "BP" is the Baxter-King Band-Pass filter, "CF" is the asymmetric Christiano-Fitzgerald filter, "DIFF" refers to simple log differences, and "HP" is the Hodrick-Prescott filter.

	Full	OECD	EU
Mean	0.31	0.34	0.33
Median	0.36	0.39	0.38
Maximum	0.97	0.94	0.93
Minimum	-0.79	-0.76	-0.79
Std. Dev.	0.38	0.36	0.39
Skewness	-0.46	-0.63	-0.57
Kurtosis	2.46	2.76	2.61
Obs.	1,027	428	270

Table 5.2 GDP correlation - Summary statistics. The table is based on HP-filtered annual times series.

	ρ	T	F_{FDI}	F_{PF}	F_{EQ}	F_{DB}	S
			Whole sample				
ρ	1.00						
T	0.08	1.00					
F_{FDI}	0.30	0.10	1.00				
F_{PF}	0.25	-0.02	0.76	1.00			
F_{EQ}	0.19	-0.02	0.76	0.92	1.00		
F_{DB}	0.27	-0.00	0.73	0.97	0.84	1.00	
S	-0.20	0.03	-0.29	-0.43	-0.39	-0.43	1.00
			OECD sample				
ρ	1.00						
T	0.18	1.00					
F_{FDI}	0.42	0.21	1.00				
F_{PF}	0.41	0.09	0.79	1.00			
F_{EQ}	0.35	0.05	0.80	0.95	1.00		
F_{DB}	0.35	0.12	0.75	0.98	0.88	1.00	
S	-0.19	- 0.01	-0.29	-0.40	-0.39	-0.39	1.00
			EU sample				
ρ	1.00						
T	0.03	1.00					
F_{FDI}	0.37	0.09	1.00				
F_{PF}	0.35	- 0.09	0.80	1.00			
F_{EQ}	0.35	0.01	0.78	0.93	1.00		
F_{DB}	0.34	- 0.13	0.78	0.99	0.89	1.00	
S	-0.25	- 0.06	-0.32	-0.46	-0.41	-0.45	1.00

Table 5.3 Unconditional correlations. All variables measured in logs, except for ρ. ρ measures the bilateral GDP correlation on the basis of HP-filtered annual data. T is the measure of bilateral trade described in the text. F_{FDI}, F_{PF}, F_{EQ} and F_{DB} are the measures of bilateral financial asset holdings based on foreign direct investment, portfolio investment, equity and debt holdings, respectively. S measures the cross-country similarity in production structures.

	Measure of F				
	F_{FDI}	F_{PF}	F_{EQ}	F_{DB}	$\widetilde{F}_{FDI}$
(1) GDP correlation					
Trade links (α_1)	0.05	0.04	0.04	0.02	0.05
	(3.06)	(3.24)	(3.10)	(1.69)	(1.90)
Fin. links (α_2)	-0.02	-0.01	0.00	0.02	-0.01
	(-1.38)	(-1.20)	(0.10)	(1.82)	(-0.42)
Prod. struct. (α_3)	-0.23	-0.26	-0.22	- 0.12	-0.21
	(-4.50)	(-4.81)	(-3.91)	(-1.83)	(-4.19)
(2) Trade links T					
Fin. links (β_1)	-0.07	-0.05	-0.08	-0.10	-0.32
	(-2.18)	(-2.22)	(-2.95)	(-2.73)	(-3.01)
Prod. struct. (β_2)	-0.23	-0.37	-0.31	-0.38	-0.36
	(-1.55)	(-2.59)	(-2.01)	(-2.14)	(-1.73)
(3) Prod. struct.S					
Trade links (γ_1)	0.14	0.07	0.07	0.07	0.36
	(4.56)	(3.65)	(2.84)	(3.17)	(6.34)
Fin. links (γ_2)	- 0.20	- 0.10	- 0.12	-0.12	- 0.35
	(-8.42)	(-9.31)	(-7.36)	(-7.92)	(-7.16)
Obs.	853	964	756	814	790

Table 5.4 Estimation results - full sample. All variables measured in logs, except for ρ. ρ measures the bilateral GDP correlation on the basis of HP-filtered annual data. T is the measure of bilateral trade described in the main text. F_{FDI}, F_{PF}, F_{EQ}, F_{DB} are the measures of bilateral financial asset holdings based on foreign direct investment, portfolio investment, equity and debt holdings, respectively. $\widetilde{F}_{FDI}$ is the alternative measure of financial linkages, which corrects for country size (based on FDI holdings). S measures the cross-country similarity in production structures. Estimation using 3SLS, with instruments described in the main text. t-statistics in parentheses.

	Measure of F			
	F_{FDI}	F_{PF}	F_{EQ}	F_{DB}
(1) GDP correlation				
Trade links (α_1)	0.07	0.07	0.07	0.07
	(3.12)	(4.46)	(4.56)	(3.87)
Fin. links (α_2)	0.02	0.02	0.02	0.04
	(1.03)	(1.13)	(1.54)	(2.33)
Prod. struct. (α_3)	-0.19	-0.17	-0.18	- 0.13
	(-3.13)	(-2.50)	(-2.52)	(-1.94)
(2) Trade links T				
Fin. links (β_1)	-0.03	-0.07	-0.12	-0.20
	(-0.62)	(-1.75)	(-3.09)	(-3.50)
Prod. struct. (β_2)	- 0.34	- 0.60	- 0.65	-0.93
	(-2.00)	(-2.94)	(-3.53)	(-3.93)
(3) Prod. struct.S				
Trade links (γ_1)	0.19	0.08	0.06	0.09
	(4.43)	(2.97)	(2.15)	(3.10)
Fin. links (γ_2)	- 0.23	- 0.15	- 0.17	-0.16
	(-6.74)	(-9.16)	(-8.04)	(-8.30)
Obs.	416	421	391	393

Table 5.5 Estimation results - OECD sample. All variables measured in logs, except for ρ. ρ measures the bilateral GDP correlation on the basis of HP-filtered annual data. T is the measure of bilateral trade described in the main text. F_{FDI}, F_{PF}, F_{EQ}, F_{DB} are the measures of bilateral financial asset holdings based on foreign direct investment, portfolio investment, equity and debt holdings, respectively. S measures the cross-country similarity in production structures. Estimation using 3SLS, with instruments described in the main text. t-statistics in parentheses.

	Measure of F			
	F_{FDI}	F_{PF}	F_{EQ}	F_{DB}
(1) GDP correlation				
Trade links (α_1)	0.03	0.06	0.04	0.07
	(1.05)	(2.12)	(1.54)	(2.31)
Fin. links (α_2)	0.04	0.03	0.02	0.04
	(2.91)	(2.52)	(1.52)	(3.14)
Prod. struct. (α_3)	-0.19	-0.21	-0.27	- 0.15
	(-2.64)	(-2.61)	(-3.49)	(-1.74)
(2) Trade links T				
Fin. links (β_1)	-0.11	-0.11	-0.10	-0.13
	(-3.54)	(-4.25)	(-3.99)	(-4.53)
Prod. struct. (β_2)	- 0.16	- 0.06	- 0.23	-0.53
	(-1.04)	(-1.29)	(-1.49)	(-3.21)
(3) Prod. struct.S				
Trade links (γ_1)	0.06	- 0.06	- 0.03	- 0.07
	(0.92)	(-1.29)	(-0.60)	(-1.28)
Fin. links (γ_2)	- 0.13	- 0.09	- 0.08	-0.10
	(-4.96)	(-5.60)	(-4.87)	(-5.83)
Obs.	251	268	242	265

Table 5.6 Estimation results - EU sample. All variables measured in logs, except for ρ. ρ measures the bilateral GDP correlation on the basis of HP-filtered annual data. T is the measure of bilateral trade described in the main text. F_{FDI}, F_{PF}, F_{EQ}, F_{DB} are the measures of bilateral financial asset holdings based on foreign direct investment, portfolio investment, equity and debt holdings, respectively. S measures the cross-country similarity in production structures. Estimation using 3SLS, with instruments described in the main text. t-statistics in parentheses.

	Estimator			
	3SLS	OLS	2SLS	GMM
(1) GDP correlation				
Trade links (α_1)	0.05	0.00	0.04	0.05
	(3.06)	(-0.11)	(2.53)	(3.25)
Fin. links (α_2)	-0.02	0.02	-0.01	-0.02
	(-1.38)	(4.06)	(-0.59)	(-1.39)
Prod. struct. (α_3)	-0.23	-0.08	-0.18	-0.23
	(-4.50)	(-3.75)	(-3.44)	(-4.30)
(2) Trade links T				
Fin. links (β_1)	-0.07	0.00	-0.07	-0.04
	(-2.18)	(0.44)	(-2.08)	(-1.37)
Prod. struct. (β_2)	-0.23	-0.03	-0.22	-0.11
	(-1.55)	(-0.63)	(-1.48)	(-0.82)
(3) Prod. struct.S				
Trade links (γ_1)	0.14	0.01	0.14	0.14
	(4.56)	(0.47)	(4.61)	(4.92)
Fin. links (γ_2)	-0.20	-0.06	-0.20	-0.21
	(-8.42)	(-8.93)	(-8.35)	(-10.06)
Obs.	853	853	853	853

Table 5.7 Estimation results using alternative estimators (full sample, F measured by FDI). All variables measured in logs, except for ρ. ρ measures the bilateral GDP correlation on the basis of HP-filtered annual data. T is the measure of bilateral trade described in the main text. S measures the cross-country similarity in production structures. t-statistics in parentheses.

	Sample		
	Whole	OECD	EU
Trade channel			
Direct (α_1)	0.05***	0.07**	0.03
Indirect			
via prod. struct. ($\alpha_3\gamma_1$)	-0.03***	-0.04**	- 0.01
Overall ($\alpha_1 + \alpha_3\gamma_1$)	0.01	0.02*	0.02
Prod. struct. channel			
Direct (α_3)	-0.23***	-0.19***	- 0.19***
Indirect			
via trade ($\alpha_1\beta_2$)	- 0.01	- 0.02*	- 0.00
Overall ($\alpha_3 + \alpha_1\beta_2$)	-0.25***	-0.21***	- 0.19***
Financial channel			
Direct (α_2)	- 0.02	0.02	0.04***
Indirect			
via trade ($\alpha_1\beta_1$)	-0.00*	- 0.00	- 0.00
via prod. struct. ($\alpha_3\gamma_2$)	0.05***	0.04***	0.02**
Overall (see below)	0.03***	0.06***	0.06***

Table 5.8 Channels of business cycle synchronization (with F measured by FDI). The values are computed on the basis of the estimates reported in Tables 5.4, 5.5 and 5.6. The derivation of the overall effect of financial integration is discussed in the main text. ***/**/* denote (joint) significance at the 1%, 5%, and 10% levels.

	Sample		
	Whole	OECD	EU
Trade channel			
Direct (α_1)	0.04***	0.07***	0.06**
Indirect			
via prod. struct. ($\alpha_3\gamma_1$)	-0.02**	-0.01*	0.01
Overall ($\alpha_1 + \alpha_3\gamma_1$)	0.02*	0.06***	0.07**
Prod. struct. channel			
Direct (α_3)	-0.26**	-0.17***	- 0.21***
Indirect			
via trade ($\alpha_1\beta_2$)	- 0.02**	- 0.04**	- 0.03*
Overall ($\alpha_3 + \alpha_1\beta_2$)	-0.27***	-0.21***	- 0.24***
Financial channel			
Direct (α_2)	- 0.01	0.02	0.03**
Indirect			
via trade ($\alpha_1\beta_1$)	- 0.00*	- 0.01*	- 0.01*
via prod. struct. ($\alpha_3\gamma_2$)	0.03***	0.03**	0.02**
Overall (see below)	0.01***	0.04***	0.04***

Table 5.9 Channels of business cycle synchronization (with F measured by portfolio investment). The values are computed on the basis of the estimates reported in Tables 5.4, 5.5 and 5.6. The derivation of the overall effect of financial integration is discussed in the main text. ***/**/* denote (joint) significance at the 1%, 5%, and 10% levels.

	Instruments			
	Schindler (2009)		La Porta et al. (1998)	
Measure of F	F_{FDI}	F_{PF}	F_{FDI}	F_{PF}
	Whole Sample			
Direct	-0.02	-0.01	0.01	-0.01
Overall	0.03***	0.01***	0.02***	0.03***
	OECD Sample			
Direct	0.02	0.02	0.05***	0.04***
Overall	0.06***	0.04***	0.06***	0.05***
	EU Sample			
Direct	0.04***	0.03**	0.04***	0.02
Overall	0.06***	0.04***	0.06***	0.05***

Table 5.10 Effects of financial linkages on output co-movement - Alternative sets of instruments. F_{FDI} and F_{PF} are the measures of bilateral financial asset holdings based on respectively foreign direct investment and portfolio investment. The derivation of the direct and overall effects is the same as for Tables 5.8 and 5.9. ***/**/* denote (joint) significance at the 1%, 5%, and 10% levels.

5.6.2 Data sources

Variables	Data	Sources	No. Countries
Output correl. (ρ)	GDP	IMF IFS	56
Trade links (T)	Exports	IMF DOTS	56
	Imports	IMF DOTS	56
	World nominal GDP	IMF IFS	56
Financial links (F)	FDI holdings	OECD FDI Statistics	source: 30
			destin.: 56
	Portfolio Investment	IMF CPIS	source: 30
			destin.: 56
Prod. struct. (S)	Sector share in value added	UNIDO	56
Instruments for:			
Trade (I_2)	Bilateral distance	CEPII	56
	Common border	CEPII	56
	Past single jurisdiction	CEPII	56
Prod. struct. (I_3)	GDP per capita	United Nations	56
Finance (I_4)	Financial restrictions	Schindler (2009)	56
	FDI restrictions	Schindler (2009)	56
	Other (see main text)	La Porta et al. (1998)	39

Table 5.11 Data sources. The variables are computed as averages over 1993-2007, except FDI holdings (2000-06), portfolio investment (2001-07) and production structure (2000-07). IFS: International Financial Statistics; DOTS: Direction of Trade Statistics; CPIS: Coordinated Portfolio Investment Survey. For the production structure (S), UNIDO data on gross value added for six broad sectors are used: Agriculture, hunting, forestry, fishing (ISIC A-B); mining, manufacturing, utilities (ISIC C-E); construction (ISIC F); wholesale, retail trade, restaurants and hotels (ISIC G-H); transport, storage and communication (ISIC I); other Activities (ISIC J-P).

5.6.3 Country groups

Full sample (56 countries): Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Chile, Colombia, Costa Rica, Cyprus, Czech Republic, Denmark, Egypt, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Japan, Latvia, Korea, Luxembourg, Malaysia, Malta, Mauritius, Mexico, Netherlands, New Zealand, Norway, Pakistan, Panama, Philippines, Poland, Portugal, Romania, Russia, Slovak Republic, South Africa,

Spain, Sweden, Switzerland, Thailand, Turkey, Ukraine, United Kingdom, United States, Uruguay, Venezuela.

OECD economies (30 countries): Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.

EU sample (25 countries):[15] Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Spain, Sweden, United Kingdom.

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[15]For data availability reasons, Slovenia and Lithuania have not been included in the panel.

Chapter 6

Concluding remarks

Facilitated by technical advances and economic liberalization, the division of labor is now operating at a finer level of resolution than at any point in history (Baldwin 2006). As a result, the world economy is increasingly permeated by vertical linkages. Production chains nowadays often run across several borders, with parts and components being shipped across the globe. Not only can production and consumption occur at a distance (as has been the case almost since time immemorial), but it is becoming increasingly viable to spatially separate individual production stages that used to be concentrated in a single factory. By the same token, a product's country of origin is becoming an elusive concept.

In many advanced and emerging economies, the share of imported intermediates in total intermediates used in the manufacturing sector has increased significantly over the past two decades (see Chapter 1). In larger European economies, including Germany, around one-third of all intermediates are nowadays imported from abroad. Small, open economies that are tightly integrated into international production networks import more than two-thirds of their intermediates. As a result, trade in final goods increasingly embodies foreign value added.

When vertical linkages - or offshoring, for that matter - gradually came into the limelight in the 1990s, both the public debate and academic research were at first primarily concerned with potential labor market effects. This narrow focus, while understandable, misses the fact that the rise of vertical linkages has also had profound consequences for international trade and macroeconomic dynamics. This dissertation has highlighted some of these impacts, which have so far received only little attention in the literature.

Chapter 2 proposed a novel way of linking the rise of vertical linkages and the stunning increase in world trade in the two decades preceding the global downturn of 2008-09. Conventional wisdom has it that the increase in world trade is largely a statistical artifact. Since trade is measured in gross terms, the argument goes, the international fragmentation of production implies that ever larger trade

flows are recorded, even if the value added exchanged between countries remains unchanged. However, this narrative misses an important element. Based on a general equilibrium model with heterogeneous firms, I showed analytically that a decline in offshoring costs fosters not only trade in intermediates but also trade in final goods through an intra-industry reallocation of resources towards the more productive and export-prone firms. Unlike existing explanations, the underlying mechanism - the "export-magnification effect of offshoring" - is consistent with the fact that the share of intermediates in total world trade has remained broadly stable over recent years. In the model, lower offshoring costs trigger a Darwinian selection process in which the most productive firms flourish at the expense of the less productive firms, with positive effects on aggregate productivity and welfare. That some firms benefit from extended offshoring possibilities, while others, within the same industry, are worse off, is a good example of the fine-brushed welfare impacts of the present wave of globalization, in which winners and losers are often hard to identify ex ante, as highlighted by Baldwin (2008).

The next chapters made the point that vertical linkages are not only relevant for international trade, but also deserve greater attention in the field of international macroeconomics. After all, vertical linkages establish a finely woven channel system through which shocks are transmitted rapidly across the globe. While the intuition is straightforward, the exact impacts on the second moments of macro variables are still poorly understood. To some extent, this reflects the fact that the international fragmentation of production has so far been primarily dealt with from the static, deterministic perspective of trade theory. Chapters 3 and 4 can be seen as a step towards closing this gap.

Chapter 3 demonstrated, in the context of a minimal IRBC model, that more extensive vertical linkages increase the sensitivity of international trade to macroeconomic shocks and, under certain conditions, the cross-country synchronization of trade flows. In the light of the expansion of vertical linkages over the past two decades, these findings provide an intuitive explanation for the fact that international trade flows have become more volatile over this period, also relative to output. The results also improve our understanding of the highly synchronized contraction in international trade in 2008-09. Vertical linkages helped amplify and propagate the shock that hit the world economy at the time. This "structural" explanation complements other narratives related to, say, demand composition effects, the inventory cycle, or financial factors.

That trade becomes more volatile as vertical linkages expand may appear somewhat disturbing at first sight. It should be noted, however, that this outcome reflects a (constrained) Pareto-efficient allocation of resources. Attempts to obstruct the development of international supply chains would therefore clearly be mistaken, also due to the other long-run welfare gains offered by the vertical frag-

mentation of production (Kohler 2004*a*).

Chapter 4 put under scrutiny the standard modeling of vertical linkages in DSGE models. In a workhorse DGSE model, domestic and foreign intermediates are typically bundled together using Armington aggregators. This implies that firms adjust only the quantities of imported intermediates (intensive margin), while the range of imported intermediates (extensive margin) is exogenously fixed. Chapter 4 departed from this standard modeling strategy. More specifically, I constructed a medium-scale DSGE model in which both the intensive and the extensive margins of offshoring are endogenous. In this comprehensive framework, it was shown numerically that endogeneity of the extensive margin hardly affects the model dynamics in the face of standard macroeconomic shocks. Furthermore, the extensive margin was found to be rather unresponsive at business cycle frequency. I concluded that, while offshoring as such has important implications for macro dynamics, the phenomenon can safely be studied using Armington aggregators. This modeling strategy has clear advantages both in terms of modeling parsimony and the availability of benchmark parameter values widely used in the literature. These findings also justified the modeling approach chosen in the previous chapter.

Taken together, the findings of Chapters 2 and 3 suggest that a world with more vertical linkages is also one in which national business cycles move more closely together: vertical linkages stimulate international trade, which, in turn, is conducive to closer business cycle synchronization. This conjecture is indeed in line with Kose and Yi (2001, 2006) who demonstrate both theoretically and empirically that the international fragmentation of production raises output co-movement. Notwithstanding this, economic integration - or globalization, for that matter - has progressed not only in the form of sprawling vertical linkages but also in other parts of the economy, particularly in financial markets. Against this backdrop, Chapter 5 examined the determinants of international output co-movement in greater detail and disentangled the various channels based on a simultaneous equations approach. The results confirm that trade linkages and similar production structures are conducive to highly synchronized business cycles. By contrast, there is no evidence of a direct impact of closer financial ties on the correlation of national GDPs. However, financial integration indirectly raises business cycle synchronization by increasing the similarity of production structures. The chapter went beyond the existing literature in that it also considered FDI linkages as a channel for the international transmission of shocks. It was shown that FDI and portfolio investment have very similar effects on business cycle synchronization. The chapter also presented some tentative evidence indicating that shock transmission through financial channels is more relevant among the industrialized economies compared with the mixed sample of advanced and emerging economies.

In summary, it seems fair to conclude that the spreading of vertical linkages has

had profound consequences for international trade and macroeconomic dynamics. Above all, the expansion of vertical linkages has been a driving force behind the longer-term increase in world trade. For one thing, the international fragmentation of production means that goods and their components cross borders several times before arriving at their final destination. Since trade is measured in gross terms, this process inflates the flow of commodities. For another thing, the decline in offshoring costs has also triggered an intra-industry reallocation of resources towards the more productive, export-oriented final goods producers, with stimulating effects on trade in final goods. Furthermore, vertical linkages establish a channel system through which macroeconomic shocks are rapidly transmitted across national borders. It is not surprising, therefore, that the rise of vertical linkages has amplified the short-run volatility and cross-country synchronization of international trade flows. More generally, the expansion of vertical linkages has contributed to the ongoing integration of the global economy, both directly and indirectly, through increased trade in final goods. In such a tightly interconnected world, national business cycles increasingly move in sync. In essence, a more and more fine-brushed division of labor spawns ever larger trade flows that are flowing in a more volatile and synchronized fashion across the globe, adding to the integration of the global economy.

Looking ahead, the expansion of vertical linkages is likely to continue over the medium term as long as the underlying technological and political driving forces endure. While it stands to reason that technological advances will keep lowering distance costs over the years ahead, the political dimension is more uncertain. The decline of distance costs could easily be interrupted or even reversed by political measures, just as the previous phase of globalization was brought to an end during the inter-war period.[1] In an environment of lackluster growth and unemployment at historically high levels in many advanced economies, policy makers may be increasingly tempted to succumb to protectionist pressures to stimulate growth in the short run in a "beggar-thy-neighbor" fashion. Looking at evidence from the Great Depression of the 1930s, Eichengreen and Irwin (2010) find that governments were more likely to resort to protectionist measures if other policy options were exhausted. In this sense, protectionism was seen as a second-best macroeconomic policy in the face of constraints on monetary and fiscal policy. This does not bode well for the near-term future. Many economies are facing sovereign debt levels and sovereign spreads at elevated, if not unsustainable levels and, in some economies, conventional monetary policy is facing the zero lower bound. Hence, the room for manoeuvre for fiscal and monetary policy is very limited in these economies, which could prompt policy makers to impose protectionist measures.

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[1]An authoritative account of the different phases of globalization is provided by Bordo et al. (1999).

While internationally fragmented production networks would be particularly vulnerable in case of a protectionist backlash, they could also make this outcome less likely. In the presence of international supply chains, tariffs and other artificial trade barriers are set to raise the costs of imports used as inputs in some domestic industries, resulting in a cost-push shock for domestic firms. To the extent that policy makers are concerned about the fate of firms and workers in these industries, they might be less inclined to impose import barriers in the first place. Indeed, Gawande, Hoekman and Cui (2011) find that greater dependence on vertical linkages was the most important factor explaining why some countries were less prone than others to impose trade-restricting measures in the wake of the global economic downturn of 2008-09. Against this backdrop, it stands to reason that vertical linkages will continue to play an important role in the global economy over the years ahead. In the words of Adam Smith, a continuation of the decline in distance costs and the ensuing international fragmentation of production would greatly enhance the "productive powers of labour", one of the cornerstones of contemporary prosperity.

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