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2 A general equilibrium theory for estimating gravity equations of bilateral FDI, final goods trade, and intermediate trade flows

J. H. Bergstrand and P. Egger

> I think that we have spent way too much time on differentiated final goods, and neglected trade in intermediates . . . intermediates-inputs approach seems empirically very relevant, and formal econometric work would be very welcome.
>
> (James Markusen, interview in Leamer 2001, p. 382)

1 Introduction

Contrary to popular hype, the vast bulk of intermediates trade – that is, outsourcing – is *among* developed countries, not between developed and developing countries. This is consistent with Jabbour (2007), who showed in an extensive empirical analysis of 4,305 French firms (using survey data) that the vast bulk import their intermediate inputs from *other developed economies* through *arm's-length transactions*. Consequently, most intermediates trade is intra-industry (and likely "Ethier-type" intermediates trade). Because of the previous absence of a comprehensive dataset on intermediates and final goods trade flows, econometric analysis of the *determinants* of intermediates trade volumes/values is virtually non-existent, as our quote from Markusen (2001) suggests.[1] Egger and Egger (2005) provide one of only two empirical (gravity) analyses of a narrow aspect of outsourcing trade flows – bilateral "processing" trade among twelve European Union economies by national and multinational enterprises. The other empirical study is Baldone *et al.* (2002).[2] Aside

[1] Most of the empirical analyses of the consequences of outsourcing have had to focus instead on *multilateral* issues, such as relative price effects (that is, the effects on the "wage skill premium"), and for only a few specific countries.

[2] "Processing trade" refers to intermediates goods imports (exports) of countries that are "processed" (or value is added) in a special economic "zone" without tariffs imposed,

from these two empirical analyses, the absence of systematic intermediates versus final goods trade data has confined many researchers of outsourcing to employing numerical simulations to study final and intermediates trade volumes (see Baier and Bergstrand 2000 and Yi 2003). Moreover, the absence of bilateral trade data decomposed by final versus intermediate goods has resulted in no motivation for developing a theoretical foundation for (separate) gravity equations for final goods bilateral trade versus intermediates bilateral trade – much less one that accounts for multinational enterprises, FDI, and potential consequences of outsourcing for these factors. As Markusen's quote suggests, it is now time to pursue "formal econometric work" on the determinants of intermediates trade flows – with Ethier-type intermediates trade in mind.

Consequently, in the spirit of the "Knowledge-Capital" model in Markusen (2002) and the "Knowledge-and-Physical-Capital" model in Bergstrand and Egger (2007), we develop a three-factor, three-country, three-good general equilibrium model of multinational and national firms with intermediates. A numerical version of the general equilibrium (GE) model motivates a theoretical rationale for estimating gravity equations of bilateral intermediate goods trade – and in a manner consistent with estimating gravity equations of bilateral final goods trade and FDI flows. Interestingly, the theoretical gravity equations for all three types of flows are *not exactly the same*, and we use the GE model to explain the slightly different theoretically motivated gravity specifications.[3] We find that economic size-related Ethier-type trade explains empirically the *vast bulk* of the variation in bilateral intermediates international trade flows. Moreover, we provide empirical evidence that bilateral final goods trade flows, intermediates trade flows, and FDI flows are all driven by a "common process." This conclusion is important because it implies that previous gravity equations of bilateral trade (FDI) flows including on the RHS bilateral FDI (trade) flows are seriously mis-specified, likely suffering from endogeneity bias.

The remainder of the paper is as follows. Section 2 motivates the analysis and discusses the construction of our new dataset of annual bilateral final goods and intermediate goods trade flows among 160 countries for the period 1990–2000. Section 3 presents the theoretical framework.

and then are re-exported to the original country with tariff exemption again. This is economically a very small portion of these countries' intermediates trade. Another empirical analysis (non-gravity equation) of processing trade is Görg (2000).

[3] The introduction of intermediate goods introduces a complexity not present in Bergstrand and Egger (2007), which did not distinguish between final and intermediates goods. Markusen (2002, chapter 9) introduced a traded intermediate input; however, he assumed (for some "exogenous reason") it could be produced in only one country (which precluded two-way trade).

Section 4 summarizes the calibration of our theoretical model. Section 5 provides numerical results using our model suggesting a theoretical rationale for estimating gravity equations for bilateral final goods trade, intermediate goods trade, and FDI flows. Section 6 provides the empirical gravity equation results. Section 7 concludes.

2 Decomposing aggregate bilateral trade flows into final and intermediate goods trade flows

Recent books in the popular press such as Thomas Friedman's *The World is Flat* (2005) and associated newspaper articles on international "outsourcing" (also known as "fragmentation" or "slicing up the value chain") of intermediate stages of production suggest that the bulk of outsourcing is due to differences between countries in the cost of labor (relative wage rates). The stories suggest that increased international imports of developed economies from developing economies or increased outward FDI of developing countries to developed countries dominate international trade and FDI flows, respectively, in the past several years. However, it is useful first to look at the data – which suggest a *much different* story.

Table 2.1a presents a decomposition of international trade and FDI flows between and among developed and developing economies between 1990 and 2000. The first panel in the upper left corner of Table 2.1a provides data on the share of world trade flows (where, for empirical purposes, our "world" consists of 160 countries) among two groupings of economies, developed and developing. For empirical purposes, we consider the original 24 members of the Organization for Economic Cooperation and Development (OECD) as the "developed" economies and another 136 economies as the "developing" (or non-OECD) economies; in 1990 (our sample's beginning year) the OECD had only 24 members. As this panel shows, more than half of world trade flows are among the 24 richest (highest per capita income) economies in the world, which comprise only one-sixth of the number of countries in our sample. Moreover, only 15 per cent of OECD imports come from the developing economies – which contrasts sharply with the suggestions of *The World is Flat* and similar newspaper articles.

The panel in the upper right of Table 2.1a shows that (outward) FDI flows are also concentrated among the developed economies, in similar proportions to trade flows. 58 per cent of all outward FDI was among the 24 richest countries in the world. Thus, if multinational firms of OECD economies are investing abroad, the *vast bulk* of their FDI is with similar high per capita income economies, not with the developing world. Only 20 per cent of world outward FDI flows are from developed- to developing economies. Therefore, as has been established in such

Table 2.1a. *Distribution of goods export flows and stocks of outward FDI among 24 OECD and 136 non-OECD countries (1990–2000)*

	Total goods exports			Outward FDI stocks	
	Importers			Hosts	
Exporters	OECD	Non-OECD	Parents	OECD	Non-OECD
OECD	55.56	19.89	OECD	57.58	20.32
Non-OECD	14.69	9.86	Non-OECD	16.50	5.60
	Final goods exports			**Intermediate goods exports**	
	Importers			Importers	
Exporters	OECD	Non-OECD	Exporters	OECD	Non-OECD
OECD	56.12	18.37	OECD	54.89	21.71
Non-OECD	16.72	8.79	Non-OECD	12.26	11.14

Table 2.1b. *Average annual growth of goods export flows and stocks of outward FDI among 24 OECD and 136 non-OECD countries (1990–2000)*

	Total goods exports			Outward FDI stocks	
	Importers			Hosts	
Exporters	OECD	Non-OECD	Parents	OECD	Non-OECD
OECD	4.21	7.70	OECD	13.15	10.12
Non-OECD	15.22	19.25	Non-OECD	18.92	9.40
	Final goods exports			**Intermediate goods exports**	
	Importers			Importers	
Exporters	OECD	Non-OECD	Exporters	OECD	Non-OECD
OECD	4.41	6.98	OECD	3.96	8.38
Non-OECD	14.57	18.46	Non-OECD	16.27	19.97

Notes: There are 24 OECD and 136 non-OECD countries in the data. Intermediate goods exports account for about 46 per cent of total exports in the data (for old OECD definition see the Appendix). FDI figures are based on data from the OECD (*Foreign Direct Investment Statistics Yearbook 2006*) and UNCTAD (Major FDI Indicators; *World Investment Report 2007*).

sources as Markusen (2002) and Barba Navaretti and Venables (2004, *Fact 2*), the bulk of international trade *and* FDI is among a small number of similar, developed economies; Markusen (2002) and others term this "horizontal" FDI.

Yet, data such as those presented in the upper panels of Table 2.1a are quite well known and are readily obtainable. *Much less known* is the information in the bottom two panels of Table 2.1a. These two panels decompose world trade flows into final goods trade flows and intermediate goods trade flows, using the new dataset that we constructed. Before explaining these data, we provide some background. As discussed briefly in the introduction, there has been limited systematic empirical analysis of international outsourcing of intermediates production owing to a dearth of comprehensive data decomposing trade into final and intermediate products.[4] As Feenstra (1994) notes, there have been only a few selected empirical treatments of outsourcing, which he cites. For instance, even though input-output tables exist for the United States and a few other industrialized economies, the US Input-Output (I-O) tables do not decompose intermediate inputs into imported and domestically produced intermediates (Feenstra 1994, p. 38). However, Feenstra and Hanson (1999) combine US industry data with US economy-wide I-O tables to calculate the increased share of imported intermediates in production in the United States. Campa and Goldberg (1997) perform similar calculations for Canada, Japan, the United Kingdom, and the United States and show similar trends, except for Japan. Hummels, Rapaport, and Yi (1998); Hummels, Ishii, and Yi (2001); and Yi (2003) do like computations for ten OECD economies to demonstrate increased outsourcing or – in their framework – increased "vertical specialization."

However, none of these studies or others has made an attempt to build a comprehensive dataset of bilateral trade flows for final and intermediates trade flows, starting with highly disaggregated bilateral trade flow data. Using the United Nations' (UN's) COMTRADE database, we aggregated five-digit Standard International Trade Classification (SITC) bilateral trade flows into (aggregate) bilateral final goods trade flows and bilateral intermediate goods trade flows according to the UN's *Classification by Broad Economic Categories* (2003), which distinguishes intermediates from final (consumer and capital) goods. The final goods trade flows aggregate 1,561 five-digit SITC categories and the intermediate goods trade flows aggregate 1,560 different five-digit SITC categories. Table 2.2 shows a decomposition into final and intermediates of the 3,121 economic categories used to create the two aggregates.

[4] A more typical decomposition of aggregate trade has been by industry classification rather than by final versus intermediates classification. Also, we note now that our intermediates (or final goods) data includes "intra-firm" intermediates trade, that is, intermediates trade between an MNE and an affiliate abroad; such trade is more accurately termed "offshoring" rather than outsourcing (since the latter is an arm's-length transaction). As we will address later, the share of intra-firm trade in total trade has been quite constant over time (especially within our sample).

Table 2.2. *Classification of Broad Economic Categories (BEC), revision 3, in terms of standard international trade classification five-digit lines*

Broad Economic Categories, revision 3, code	Number of SITC five-digit lines covered	Of which classified as intermediates
1 – Food and beverages	372	113
11 – Primary	140	44
111 – Mainly for industry	44	44
112 – Mainly for household consumption	96	0
12 – Processed	232	69
121 – Mainly for industry	69	69
122 – Mainly for household consumption	163	0
2 – Industrial supplies not elsewhere specified	1,526	1,107
21 – Primary	228	228
22 – Processed	1,298	879
3 – Fuels and lubricants	32	9
31 – Primary	9	9
32 – Processed	23	0
321 – Motor spirit	1	0
322 – Other	22	0
4 – Capital goods (except transport equipment), and parts and accessories thereof	637	273
41 – Capital goods (except transport equipment)	435	71
42 – Parts and accessories	202	202
5 – Transport equipment and parts and accessories thereof	112	58
51 – Passenger motor cars	1	0
52 – Other	53	0
53 – Parts and accessories	58	58
6 – Consumer goods not elsewhere specified	428	0
61 – Durable	96	0
62 – Semi-durable	208	0
63 – Non-durable	124	0
7 – Goods not elsewhere specified	14	0
Total	3,121	1,560

Notes: Source is the United Nations' Statistics Division. The total number of headings classified as intermediate goods is 1,560. The remaining categories are final goods.

The bottom two panels of Table 2.1a show the shares of world final goods and intermediate goods trade flows between and among OECD and non-OECD countries. The most notable conclusion is the striking similarity of the pattern of trade flows in final and intermediate goods. For *both* types of goods, approximately 55–56 per cent of world trade flows are among the OECD countries. Moreover, the remaining shares are also nearly identical to those for aggregate goods exports. Furthermore, the share of intermediate goods imports of OECD countries from non-OECD countries is only 12 per cent, even smaller than the 17 per cent for final goods imports. Thus, final goods – not intermediate goods – dominate developed countries' imports from the developing world.

Such data suggest that much – if not the majority – of world intermediates trade flows are *intra-industry* trade flows among similar, high per capita income economies – as is the case for the well-documented intra-industry trade in final goods that has been the subject of theoretical and empirical study for the last thirty years, see Grubel and Lloyd (1975). This conjecture regarding data is behind Markusen's quote above suggesting Ethier's (1982) "intermediates-input approach" as a motivation for much of world trade and "formal econometric work (of intermediates trade) would be very welcome." To put it simply, just as the bulk of international trade flows are intra-industry in nature and were explained by Helpman and Krugman (1985) using a model of intra-industry trade in final goods – and Markusen (2002) and Barba Navaretti and Venables (2004) showed that the bulk of FDI flows are intra-industry (horizontal) in nature – we show here that the bulk of intermediates outsourcing is intra-industry (Ethier-type) trade in nature. This is consistent with the results in Jabbour (2007) using an empirical analysis of survey data for 4,305 French firms.

Another interesting stylized fact from our dataset is that intermediates trade growth among OECD countries (3.96 per cent annually) has been slightly less than that of final goods trade growth (4.41 per cent annually) from 1990 to 2000. These growth rates are consistent with the data discussed in Hummels, Ishii, and Yi (2001) using the same *Classification by Broad Economic Categories*. However, we note that intermediates trade growth has exceeded final goods trade growth for trade between developed and developing countries and among developing countries between 1990 and 2000, in contrast to their conclusion of a "steadily declining since 1970" intermediates trade share.

In the remainder of this paper, we provide a theoretical and empirical model to address these stylized facts. The framework will address the main economic determinants of intermediate goods trade – in a manner consistent with explaining *final* goods trade *and* FDI flows.

3 The theoretical model

In this section, we develop a theoretical model to motivate estimating gravity equations of bilateral final goods trade, intermediate goods trade, and FDI flows (simultaneously) and to explain the growth of FDI (multinational firms) relative to trade (national firms). In the spirit of Ethier (1982), a key consideration is international trade in intermediate goods among similar developed economies. Since the vast amount of outsourcing and FDI is among developed economies with similar relative factor endowments and consequently similar relative real wage rates, then one could argue that "outsourcing" in general will not have the impact upon the convergence of relative wage rates internationally that the popular press suggests.[5]

To address these issues, we need a model that explains first the relationships between multinational enterprises that invest capital directly in foreign countries, national firms that trade either final or intermediate goods, FDI flows, final goods trade flows, and intermediate goods trade flows. To address bilateral flows in a multilateral world, we need three countries. The model we develop is a three-country, three-factor, three-good model of MNEs and national enterprises with internationally immobile skilled and unskilled labor, internationally mobile physical capital, and final and intermediate goods, in the spirit of Markusen's "Knowledge-Capital" model. In fact, the "Knowledge-and-Physical-Capital" model developed in Bergstrand and Egger (2007), which is an extension of the "Knowledge-Capital" model of Markusen (2002), is a special case (with no intermediates production) of our model here.

As background, the Knowledge-and-Physical-Capital model in Bergstrand and Egger (2007) is a three-factor, three-country, two-good extension of Markusen's $2 \times 2 \times 2$ Knowledge-Capital model with national enterprises (NEs), horizontal multinational enterprises (HMNEs), and vertical multinational enterprises (VMNEs). The demand side in the Knowledge-and-Physical-Capital model is analogous to that in the Knowledge-Capital model. However, the former extends the latter in two significant ways. The first distinction is to use *three* primary factors of production: unskilled labor, skilled labor (or human/knowledge capital), and physical capital. We assume unskilled and skilled labor are immobile

[5] We do not argue that vertical FDI and inter-industry trade between developed and developing countries with differing relative factor endowments (such as the United States and China) has not grown; it has (as our Table 2.1b suggests) and has likely contributed to the rise in income inequality in developed economies. Rather, our goal *here* is to highlight, and confirm empirically, the overlooked argument that the *bulk* of outsourcing is more likely due to horizontal (intra-industry) considerations.

internationally, but physical capital is mobile in the sense that MNEs will endogenously choose the optimal allocation of domestic physical capital between home and foreign locations to maximize profits, consistent with the BEA definition of foreign "direct investment positions" using domestic and foreign-affiliate shares of real fixed investment.[6] Thus, unlike the Knowledge-Capital model, we actually have *FDI* (as well as foreign affiliate sales).[7] The introduction of a third factor – combined with an assumption that headquarters' fixed setups require home skilled labor (to represent, say, research and development [R&D] costs) while the setup of a plant in any country requires the home country's physical capital (to represent, say, equipment) – can explain "coexistence" of HMNEs and NEs for two identically sized developed countries for a wide range of parameter values (which is precluded in the Knowledge-Capital model).[8]

The second distinction of the Knowledge-and-Physical-Capital model is to introduce a "third country." The presence of the third country helps explain the "complementarity" of bilateral foreign affiliate sales (FAS) and trade with respect to a country pair's economic size and similarity and that bilateral FDI empirically tends to be maximized when the home country's GDP is larger than the host country's. Hence, the three-factor, three-country, two-good model in Bergstrand and Egger (2007) provides a theoretical foundation for estimating "gravity equations" of bilateral

[6] In the typical $2 \times 2 \times 2$ model, headquarters use home skilled labor exclusively for setups; home (foreign) plants use home (foreign) skilled labor for setups (see Markusen 2002, p. 80). With only immobile skilled and unskilled labor, the two-factor models preclude home physical capital being utilized to set up foreign plants. We often refer to the transfer of physical capital by MNEs as capital "mobility." Consistent with Markusen (2002) and the modern MNE literature, the model is "real"; there are no paper assets. In this regard, we follow the more traditional (pre-1960) literature defining capital mobility in terms of movement of physical capital, see Mundell (1957, pp. 321–23), Jones (1967), and Helpman and Razin (1983). Moreover, while physical capital can be "utilized" in different countries, "ownership" of any country's endowment of such capital is immobile; again, we follow Mundell (1957) in this regard: "Capital is here considered a physical, homogeneous factor . . . It is further assumed that capitalists qua consuming units do not move with their capital, so national taste patterns are unaltered." In reality, of course, the presence of (paper) "claims" to physical capital allows much easier "transfer" of resources and is *one* way of measuring FDI. However, the "current-cost" method of measuring FDI is related to the shares of an MNE's *real* fixed investment in plant and equipment that is allocated to the home country relative to foreign affiliate(s); this effectively measures physical capital mobility, see Borga and Yorgason (2002, p. 27). Also, (bilateral) FDI stocks are the accumulation of (bilateral) FDI flows over several periods. Since our model is static, FDI flows and stocks are necessarily identical in the model.

[7] Markusen (2002, p. 8) notes clearly that the models in his book "are addressed more closely to affiliate output and sales than to investments stocks."

[8] As in Markusen (2002), internationally immobile skilled labor still creates firm-specific intangible assets that are costlessly shared internationally by MNEs with their plants. This aspect is maintained.

FDI and aggregate trade flows *simultaneously*. However, the model in Bergstrand and Egger (2007) does not differentiate between final goods trade and intermediate goods trade.

The model in this chapter is a more general version of the model in Bergstrand and Egger (2007) by introducing a third good (intermediates) – more accurately, a *second production stage* – to distinguish final from intermediate goods. Here, we separate national firms that produce and export final goods for consumers from national firms that produce and export intermediate goods that can be purchased by other national firms that produce final goods *or* horizontal MNEs with headquarters and a plant in one country but additional plants in either one or two other countries to serve local markets *or* vertical MNEs with headquarters in one country but a plant in another country due to different relative factor endowments between the two countries. Hence, a representative intermediates firm in some country i can sell its output to final goods-producing NEs, HMNEs or VMNEs based in its own country, in another country j, or in the rest of the world (ROW). All intermediate goods purchases are "arm's-length" transactions between legally distinct entities; hence, they conform to the conventional definition of "outsourcing." Introducing domestic and international outsourcing of intermediates to the model of Bergstrand and Egger (2007) enhances dramatically the complexity of the model.[9]

3.1 Consumers

The demand side of this model (described in this section) is identical to that in Bergstrand and Egger (2007). Consumers are assumed to have a Cobb–Douglas utility function between final differentiated goods (X) and homogeneous goods (Y). Consumers' tastes for final differentiated products (e.g. manufactures) are assumed to be of the Dixit–Stiglitz constant elasticity of substitution (CES) type, as typical in trade. We let V_i denote the utility of the representative consumer in country i. Let η be the Cobb–Douglas parameter reflecting the relative importance of manufactures in utility and ε be the parameter determining the constant elasticity of substitution, σ, among these manufactured products ($\sigma \equiv 1 - \varepsilon$, $\varepsilon < 0$). Manufactures can be produced by three different firm types: national firms (n), horizontal multinational firms (h), and vertical multinational

[9] Moreover, introducing MNE intra-firm trade in intermediates introduces yet another level of complexity far beyond the scope of this paper. However, we will document later that data used in other studies suggest that the share of intra-firm trade in all intermediates trade has been *constant* (or declining) over the 1990s, the period examined in our study.

firms (v). In equilibrium, some of these firms may not exist (depending upon absolute and relative factor endowments and parameter values). These will be reflected in three sets of components in the first of two RHS bracketed terms in equation (2.1) below:

$$V_i = \left[\begin{array}{l} \sum_{j=1}^{3} n_j \left(\frac{x_{ji}^n}{1 + \tau_{Xji}} \right)^{\frac{\varepsilon}{\varepsilon-1}} \\ \quad + \left(\sum_{j=1}^{3} h_{3,j} (x_{ii}^{h_3})^{\frac{\varepsilon}{\varepsilon-1}} \right. \\ \quad + \sum_{j \neq i} h_{2,ij} (x_{ii}^{h_2})^{\frac{\varepsilon}{\varepsilon-1}} \\ \quad \left. + \sum_{j \neq i} h_{2,ji} (x_{ii}^{h_2})^{\frac{\varepsilon}{\varepsilon-1}} \right) \\ \quad + \sum_{k \neq j} \sum_{j=1}^{3} v_{kj} \left(\frac{x_{ji}^v}{1 + \tau_{Xji}} \right)^{\frac{\varepsilon}{\varepsilon-1}} \end{array} \right]^{\frac{\varepsilon-1}{\varepsilon}\eta} \left[\sum_{j=1}^{3} Y_{ji} \right]^{1-\eta} \tag{2.1}$$

The first component reflects *national* (non-MNE) firms, or NEs, that can produce final differentiated goods for the home market or export to foreign markets from a single plant in the country with their headquarters, where: x_{ji}^n denotes the (endogenous) output of country j's representative national firm in industry X sold to country i; n_j is the (endogenous) number of these national firms in j; and τ_{Xji} is the gross (shipment) trade cost of exporting X from j to i.

The second set of components reflects *horizontal* multinational firms, or HMNEs, that may have plants in either two or three countries to be "proximate" to markets to avoid trade costs; HMNEs cannot export goods. Every HMNE has a plant in its headquarters country. Let x_{ii} denote the output of a horizontal multinational firm producing in i and selling in i; $h_{3,j}$ denote the (endogenous) number of multinationals that produce in all three countries and are headquartered in j ($j = 1, 2, 3$); $h_{2,ij}$ denote the number of two-country multinationals headquartered in i with a plant also in j; and $h_{2,ji}$ denote the number of two-country multinationals headquartered in j with a plant also in i. Hence, x_{ii}^{h3} is output produced in country i (and consumed in i) of the representative three-country HMNE headquartered in country j and x_{ii}^{h2} is the output produced in country i (and consumed in i) of the representative two-country multinational firm either headquartered in i with a plant also in j or headquartered in j with a plant also in i. Note that h_2 plants arise when market size in one of the three countries is insufficient to warrant a local plant, and is more efficiently served (given transport and investment costs) by its own national firms and imports from foreign firms.

The third component reflects *vertical* multinational firms or VMNEs. VMNEs have headquarters in one country and a plant in one of the other countries, just not in the headquarters country. The primary motivation for a vertical MNE is "cost differences"; different relative factor intensities and relative factor abundances motivate separating headquarters from production into different countries. Let v_{kj} denote the number of vertical multinational firms with headquarters in k, a plant in j, and output can be sold to any country (including k). Let x_{ji}^{v} denote the output of the representative VMNE with production in j and consumption in i.[10]

In the second bracketed RHS term, let Y_{ji} denote the output of the homogenous good (e.g. agriculture) produced in country j under constant returns to scale using unskilled labor and consumed in i. Let t_{Xji} (t_{Yji}) denote the gross trade cost for shipping final differentiated (homogeneous) good X (Y) from j to i; let t_{Zji} be defined for intermediates similarly.[11] Let $t_{Xji} = 1$ for $i = j$, and analogously for t_{Yji} and t_{Zji}. It will be useful to define gross trade costs as follows:

$$t_{Xji} = (1 + b_{Xji})(1 + \tau_{Xji})$$
$$t_{Yji} = (1 + b_{Yji})(1 + \tau_{Yji})$$
$$t_{Zji} = (1 + b_{Zji})(1 + \tau_{Zji})$$

where τ denotes a "natural" trade cost of physical shipment (cif/fob − 1) of the "iceberg" type, while b represents a "policy" trade cost (i.e. tariff rate) which generates potential revenue. For instance, b_{Xji} denotes the tariff rate (e.g. $0.05 = 5$ per cent) on imports from j to i in differentiated final good X.

[10] Recently, some researchers have considered hybrid MNEs, see Grossman *et al.* (2003), Yeaple (2003), and Ekholm *et al.* (2007). The focus of these papers is much different than ours; they demonstrate conditions when an MNE pursues both horizontal and vertical integration. Research there has been directed towards understanding more clearly how multinational firms endogenously become "hybrids" in the presence of intermediate goods production and a third country. The goal of their research is to examine theoretically the sectoral factors, such as transport costs, investment costs, and headquarters setup relative to plant setup costs, driving the "optimal" structure of a multinational firm, in terms of location of plants and headquarters. Our model here could be enriched by allowing hybrid MNEs, but at a high cost of introducing a complexity that would obscure the main issues of this paper. We leave this for future research.

[11] For modeling convenience, we define Y_{ji} net of trade costs; trade costs t_{Yji} surface explicitly in the factor-endowment constraints in the Appendix.

The budget constraint of the representative consumer in country i is assumed to be:

$$\sum_{j=i}^{3} n_j p_{Xj}^{n} x_{ji}^{n} + \sum_{j=i}^{3} h_{3,j} p_{Xi}^{h_3} x_{ii}^{h_3} + \sum_{j\neq i} h_{2,ij} p_{Xi}^{h_2} x_{ii}^{h_2} + \sum_{j\neq i} h_{2,ji} p_{Xi}^{h_2} x_{ii}^{h_2}$$
$$+ \sum_{k\neq j}\sum_{j\neq i} v_{kj} p_{Xj}^{v} x_{ji}^{v} + \sum_{j=i}^{3} p_{Yj} Y_{ji}$$
$$= r_i K_i + w_{Si} S_i + w_{Ui} U_i + \sum_{j\neq i} n_j b_{Xji} p_{Xj}^{n} x_{ji}^{n}$$
$$+ \sum_{k\neq j}\sum_{j\neq i} v_{kj} b_{Xji} p_{Xj}^{v} x_{ji}^{v} + \sum_{j\neq i} b_{Yji} p_{Yj} Y_{ji} + \sum_{j\neq i} o_j b_{Zji} p_{Zj} z_{ji} \tag{2.2}$$

where p_{Xi}^{h3} (p_{Xi}^{h2}) denotes the price charged by the representative three-country (two-country) horizontal MNE with a plant in i. Let p_{Xj}^{n}, p_{Xj}^{v}, p_{Yj}, and p_{Zj} denote the prices charged by producers in j for goods X (national firms and vertical MNEs, respectively), Y, and Z, respectively. The first three RHS terms denote factor income; the last four denote tariff revenue redistributed lump-sum by the government in i back to the representative consumer. Let r_i denote the rental rate for capital in i, K_i is the capital stock in i, w_{Si} (w_{Ui}) is the wage rate for skilled (unskilled) workers in i, and S_i (U_i) is the stock of skilled (unskilled) workers in i. Let o_j denote the number of intermediate good producers in country j.

Maximizing (2.1) subject to (2.2) yields the domestic demand functions:

$$x_{ii}^{\ell} \geq \left(p_{Xi}^{\ell}\right)^{\varepsilon-1} P_{Xi}^{-\varepsilon} \eta E_i; \quad \ell = \{n, h_3, h_2, v\} \tag{2.3}$$

where E_i is the income (and expenditure) of the representative consumer in country i from equation (2.2), and

$$P_{Xi} = \left[\sum_{j=1}^{3} n_j \left(t_{Xji} p_{Xj}^{n}\right)^{\varepsilon} + \sum_{j=1}^{3} h_{3,j} \left(p_{Xi}^{h_3}\right)^{\varepsilon} + \sum_{j\neq i} h_{2,ij} \left(p_{Xi}^{h_2}\right)^{\varepsilon} \right.$$
$$\left. + \sum_{j\neq i} h_{2,ji} \left(p_{Xi}^{h_2}\right)^{\varepsilon} + \sum_{k\neq j}\sum_{j=1}^{3} v_{kj} \left(t_{Xji} p_{Xj}^{v}\right)^{\varepsilon} \right]^{\frac{1}{\varepsilon}} \tag{2.4}$$

is the corresponding CES price index. Following the literature, we assume that all firms producing in the same country face the same technology and marginal costs and we assume complementary-slackness conditions (see Markusen 2002). Hence, the mill (or ex-manufacturer) prices of all varieties in a specific country are equal in equilibrium. Then, the relationship between differentiated final goods produced in j and at home is:

$$\frac{x_{ji}}{x_{ii}} = \left(\frac{p_{Xj}}{p_{Xi}}\right)^{\varepsilon-1} t_{Xji}^{\varepsilon}(1 + b_{Xji})^{-1} \tag{2.5}$$

Hence, from now on we can omit superscripts for both prices and quantities of differentiated products for the ease of presentation. It follows that homogeneous goods demand is:

$$\sum_{j=1}^{3} Y_{ji} \geq \frac{1-\eta}{p_{Yi}} E_i \quad \perp \quad p_{Yi} \geq 0 \tag{2.6}$$

where Y_{ji} denotes output of the agriculture good of county j demanded in country i.

Beginning with the next section, the model generalizes that in Bergstrand and Egger (2007) by addressing final *and intermediates* production issues.

3.2 Final differentiated good producers

We assume that final goods can be produced in all three countries, composed potentially of intermediates from all three countries and three primary factors: skilled labor, unskilled labor, and physical capital. Each country is assumed to be endowed with exogenous amounts of skilled labor and unskilled labor, which are internationally immobile. We assume an exogenous world endowment of physical capital which is mobile internationally; physical capital moves endogenously across countries to maximize MNEs' profits. Thus, we model explicitly the endogenous determination of bilateral FDI flows. Final differentiated goods producers operate in monopolistically competitive markets, similar to Markusen (2002, chapter 6); intermediates will be discussed later in Section 2.4.

An important distinction of our model from the $2 \times 2 \times 2$ Knowledge-Capital model is that we introduce the third factor, physical capital. As summarized in Markusen (2002), the $2 \times 2 \times 2$ model has tended to use skilled labor and unskilled labor as its two internationally immobile factors. Other papers in this literature have used labor and capital, but with the latter usually assumed internationally immobile. Yet, all formal models in this class have had only two factors. Three critical assumptions for our theoretical results that follow are the existence of a third, internationally mobile factor – physical capital – and that any headquarter's setup (fixed cost) requires home skilled labor – to represent the notion of R&D – and any plant's setup in any country requires the home country's physical capital – to represent the resources needed for a domestic or foreign direct investment.[12]

Assume the production of differentiated final good X is given by the nested Cobb–Douglas–CES technology:

$$F_{Xi} = B(K_{Xi}^{\chi} + S_{Xi}^{\chi})^{\frac{\alpha}{\chi}} (U_{Xi}^{\delta} + Z_{Xi}^{\delta})^{\frac{1-\alpha}{\delta}} \tag{2.7}$$

where F_{Xi} denotes production of final goods for both the domestic and foreign markets; we assume MNEs and national enterprises (NEs) have access to the same technology. K_{Xi}, S_{Xi}, U_{Xi}, and Z_{Xi} denote the quantities used of physical capital, skilled labor (or human capital), unskilled labor, and intermediates, respectively, in country i to produce X. The specific form of the production function is motivated by three literatures. First, the Cobb–Douglas function is useful in characterizing analytically and empirically the relatively constant production shares of capital and labor. Second, early work by Griliches (1969) indicates that physical capital and human capital tend to be complements, rather than substitutes, in technology; recent evidence for this in the MNE literature is found in Slaughter (2000). This suggests nesting a CES production function within the Cobb–Douglas function to allow for the potential complementarity or substitutability of physical and human capital. Third, recent work on outsourcing suggests that intermediate goods are substitutes for unskilled labor; the second CES sub-production function allows the elasticity of substitution between intermediates and unskilled labor to exceed unity. As the latter two issues are less known to trade economists, we address them in more depth in Section 4 when we describe the calibration of the numerical general equilibrium (GE) model.

National firms and MNEs differ in fixed costs. Each NE incurs only one firm setup and one plant setup; each MNE incurs one firm setup (the cost of which is assumed larger than that of an NE, as in Markusen

[12] Note that, while physical capital can be "utilized" in different countries, the "ownership" of any country's endowment of such capital is immobile. In the typical $2 \times 2 \times 2$ model, headquarters use home skilled labor exclusively for setups; home (foreign) plants use home (foreign) labor for setups (see Markusen 2002, p. 80). With only immobile skilled and unskilled labor, these models naturally preclude home physical capital being utilized to set up foreign plants.

2002) and a plant setup for its home market and for each foreign market it endogenously enters. A horizontal MNE has a headquarters at home and plants potentially in either two or three markets to serve them; it has no exports. A vertical MNE has a headquarters at home and one plant abroad, which can export to any market.

Let Z_{Xi} denote the CES aggregate of intermediate inputs:

$$Z_{Xi} = \left[\sum_{j=1}^{3} o_j \left(\frac{z_{ji}}{t_{Zji}} \right)^{\frac{\theta}{\theta-1}} \right]^{\frac{\theta-1}{\theta}} \tag{2.8}$$

where z_{ji} denotes the output of the representative firm in country j supplying intermediates goods to country i and $\theta < 0$. The corresponding CES price index for Z_{Xi} is:

$$P_{Zi} = \left[\sum_{j=1}^{3} o_j \left(t_{Zji} p_{Zj} \right)^{\theta} \right]^{\frac{1}{\theta}} \tag{2.9}$$

Maximizing profits subject to the above technology yields the following conditional factor demands (denoted with $*$) and input coefficients:

$$K_{Xi}^{*} = F_{Xi} \underbrace{\frac{1}{B} \left(\frac{w_{Ui}}{r_i} \frac{\alpha}{1-\alpha} \right)^{1-\alpha} T_{1i}^{\frac{\alpha(\chi-1)-\chi}{\chi}} T_{2i}^{\frac{(1-\alpha)(\delta-1)}{\delta}}}_{a_{KXi}}$$

$$S_{Xi}^{*} = F_{Xi} \underbrace{\frac{1}{B} \left(\frac{w_{Ui}}{w_{Si}} \frac{\alpha}{1-\alpha} \right)^{1-\alpha} T_{2i}^{\frac{(\alpha-1)(1-\delta)}{\delta}} T_{3i}^{\frac{\alpha(\chi-1)-\chi}{\chi}}}_{a_{SXi}}$$

$$U_{Xi}^{*} = F_{Xi} \underbrace{\frac{1}{B} \left(\frac{r_i}{w_{Ui}} \frac{1-\alpha}{\alpha} \right)^{\alpha} T_{1i}^{\frac{\alpha(\chi-1)}{\chi}} T_{2i}^{\frac{\alpha(1-\delta)-1}{\delta}}}_{a_{UXi}}$$

$$Z_{Xi}^{*} = F_{Xi} \underbrace{\frac{1}{B} \left(\frac{r_i}{P_{Zi}} \frac{1-\alpha}{\alpha} \right)^{\alpha} T_{1i}^{\frac{\alpha(\chi-1)}{\chi}} T_{4i}^{\frac{\alpha(1-\delta)-1}{\delta}}}_{a_{ZXi}}$$

(2.10a–2.10d)

where B is a constant and we introduce definitions:

$$T_{1i} = 1 + \left(\frac{r_i}{w_{Si}}\right)^{\frac{\chi}{1-\chi}}; \qquad T_{2i} = 1 + \left(\frac{P_{Zi}}{w_{Ui}}\right)^{\frac{\delta}{1-\delta}};$$

$$T_{3i} = 1 + \left(\frac{w_{Si}}{r_i}\right)^{\frac{\chi}{1-\chi}}; \qquad T_{4i} = 1 + \left(\frac{w_{Ui}}{P_{Zi}}\right)^{\frac{\delta}{1-\delta}} \quad (2.11a\text{-}2.11d)$$

3.3 *Final homogeneous goods producers*

We assume that the homogeneous good (Y) is produced under constant returns to scale in perfectly competitive markets using only unskilled labor; assume the technology $Y_i = U_i\,(i = 1, 2, 3)$. In the presence of positive trade costs, we assume country 1 is the numeraire; hence, $p_{Y1} = w_{U1} = 1$.

3.4 *Intermediate differentiated goods producers*

Our model is a more general version of the three-factor, three-country, two-good model in Bergstrand and Egger (2007) to include outsourcing of intermediate goods. Outsourcing, by definition, is a trade between unaffiliated firms. Feenstra (1994) cites several empirical studies suggesting that trade in intermediates is growing faster than trade in final goods, reflecting the outsourcing issue. With much of this paper focused on MNE behavior, one might assume that our model will introduce *intra-firm* (MNE) trade in intermediates, or "intermediates offshoring." By contrast, we will assume that intermediates are produced by *national* firms (not MNE affiliates); thus, arm's-length intermediate imports generate "outsourcing," using the conventional definition.[13] However, our model allows final goods offshoring by vertical MNEs.

Importantly, the vast bulk of intermediates trade is between *unaffiliated* firms. We note several studies supporting this claim. First, data on intra-firm trade is scarce, with only the Japanese, Swedish, and US governments as possible sources. Grimwade (1989) presents data from the US Tariff Commission that indicates, in 1977, only 36 (64) per cent of total US exports were intra-firm (between unaffiliated firms); however, this data is admittedly dated. Second, Markusen (2002, chapter 1) presents US BEA data on parent-affiliate trade as a proportion of total affiliate sales with major trading partners for 1987 and 1997. Regardless

13 Of course, in the context of the model, there is costless intra-firm exchange of intangible assets of MNEs.

of year, exports vs. imports, or outward vs. inward data, parent-affiliates trade was *never more than 15 per cent* of total affiliate sales. Third, Filipe *et al.* (2002) report annual data from the US BEA specifically on intra-firm trade as a share of total US trade (by exports, imports or both) from 1989 to 1998. Interestingly, averaging imports and exports, intra-firm US trade by MNEs was at a maximum of 44 per cent in 1989–90 and actually *declined* to only 38 per cent in 1997–98, even though intermediates trade was growing as a share of final and intermediates trade in the 1990s, see Hummels, Ishii, and Yi (2001) and Yi (2003). Fourth, this is consistent with Jabbour (2007) using French firm data showing that intra-firm MNE trade is no more than 30 per cent of international offshoring. Finally, Bernard *et al.* (2005) provide data for the United States for 1993 and 2000 and show that intra-firm trade as a share of MNEs' trade was virtually constant from 1993 to 2000, precluding an increased intra-firm trade share as a possible source of increased FDI to final goods trade. These studies confirm the importance of intermediates trade among *unaffiliated* firms. To be consistent with these observations (while also limiting the model's complexity and scope), we model intermediates trade as among unaffiliated firms, even though we still allow vertical MNEs to export *final* goods from a foreign plant to a home country's consumer.[14]

We assume that differentiated intermediate products for the (national) representative (type o) firm in country i are produced in monopolistically competitive markets given a Cobb–Douglas technology:

$$z_i = AS_{Zi}^{\beta}U_{Zi}^{1-\beta} \tag{2.12}$$

where z_i denotes production of intermediate goods for both the domestic and foreign markets. Local intermediate goods supply from a single intermediate goods producer in market i for local demand is referred to as z_{ii}, whereas supply to (and, in equilibrium, demand gross of transport costs in) a foreign market j is denoted by z_{ij}. As for national final goods exporters, any (national) intermediate firm incurs one headquarters setup and one plant setup.[15] The above technology yields the

[14] In the future, one could also allow intra-firm trade in intermediates, as in Markusen (2002, chapter 9). However, at this time, this would introduce yet another level of complexity well beyond the scope of this already fairly intricate model.

[15] One might argue that – since we are precluding multinational firms in producing intermediates – there might be no reason to distinguish headquarters fixed costs from plant fixed costs, as is done for national firms producing final goods. However, as will be apparent shortly in equations (2.16a)–(2.16e), the input requirements are general enough simply to allow different relative factor requirements of human and physical capital in

following conditional factor demands and input coefficients:

$$S^*_{Zi} = z_i \underbrace{\frac{1}{A}\left(\frac{w_{Ui}}{w_{Si}}\frac{\beta}{1-\beta}\right)^{1-\beta}}_{a_{SZi}}$$

$$U^*_{Zi} = z_i \underbrace{\frac{1}{A}\left(\frac{w_{Si}}{w_{Ui}}\frac{1-\beta}{\beta}\right)^{\beta}}_{a_{UZi}} \qquad (2.13a\text{–}2.13b)$$

An intermediate goods producer in the intermediate goods market equilibrium is faced with local (domestic) demand:

$$z_{ii} \geq \left(\frac{P_{Zi}}{p_{Zi}}\right)^{1-\theta} a_{ZXi}\left[n_i \sum_{j=1}^{3} x_{ij} + x_{ii}\left(\sum_{j=1}^{3} h_{3,j} + \sum_{j\neq i} h_{2,ji} + \sum_{j\neq i} h_{2,ij}\right) + \sum_{j\neq i} v_{ji}\left(\sum_{j=1}^{3} x_{ij}\right)\right] \qquad (2.14)$$

and the relationship between foreign and domestically sourced intermediates is:

$$\frac{z_{ji}}{z_{ii}} = \left(\frac{p_{Zi}}{p_{Zj}}\right)^{1-\theta} t^{\theta}_{Zji}\left(1+b_{Zji}\right)^{-1} \qquad (2.15)$$

3.5 *Profit functions and pricing equations*

All firms are assumed to maximize profits given the technologies assumed and the demand curves suggested above. The profit functions are:

$$\pi_{oi} = (p_{Zi} - c_{Zi})\sum_{j=1}^{3} z_{ij} - a_{Soi}w_{Si} - a_{Koi}r_i$$

$$\pi_{ni} = (p_{Xi} - c_{Xi})\sum_{j=1}^{3} x_{ij} - a_{Sni}w_{Si} - a_{Kni}r_i$$

the setups of headquarters and plants for national final good and national intermediate good producers. For now, we allow each intermediates producer to "set up" a headquarters (to research, advertise, or distribute its product) and a plant.

$$\pi_{h3,i} = \sum_{j=1}^{3} (p_{Xj} - c_{Xj})x_{jj} - a_{Smi}w_{Si} - a_{Kmi}\left[3 + \sum_{j \neq i} \gamma_{ij}\right] r_i$$

$$\pi_{h2,ij} = (p_{Xi} - c_{Xi})x_{ii} + (p_{Xj} - c_{Xj})x_{jj} - a_{Smi}w_{Si} - a_{Kmi}[2 + \gamma_{ij}]r_i$$

$$\pi_{v,ij} = (p_{Xj} - c_{Xj}) \sum_{k=1}^{3} x_{jk} - a_{Smi}w_{Si} - a_{Kmi}[1 + \gamma_{ij}]r_i$$

(2.16a–2.16e)

Equation (2.16a) is the profit function for an intermediate goods producer in country i. Let c_{Zi} denote marginal costs of intermediate goods production in i and the latter two RHS terms represent fixed (domestic) skilled labor and physical capital costs for the intermediate goods producer to set up a headquarters and a plant. Equation (2.16b) is the profit function for each national final goods enterprise (NE) in i. Let c_{Xi} denote marginal production costs of differentiated final good X in country i and the latter two RHS terms represent fixed human and physical capital costs for the national enterprise final goods producer. Equation (2.16c) is the profit function for each horizontal final-good-producing multinational firm in country i with three operations (one in the parent country and one in each of two foreign markets). The last two terms in (2.16c) represent fixed costs of each three-country horizontal MNE. As with previous firms, the MNE incurs a single fixed cost of home skilled labor to set up a firm. However, each three-country MNE incurs a fixed cost of home physical capital for each plant. Moreover, each foreign investment incurs a potential investment cost γ (say, policy or natural FDI barrier). Equation (2.16d) is the profit function for each horizontal final-good-producing multinational firm in country i with two operations (one at home). Finally, equation (2.16e) is the profit function for a vertical MNE with a headquarters in i and a plant in j.

A key element of our model is that – in each country – the numbers of national intermediates producers (type o), national final goods enterprises (type n), three-country horizontal MNEs (type h_3), two-country horizontal MNEs (type h_2), and vertical MNEs (type v) are *endogenous* to the model. Two conditions characterize models in this class. First, profit maximization ensures markup pricing equations:

$$p_{Zi} \leq \frac{c_{Zi}(\theta - 1)}{\theta} \qquad p_{Xi} \leq \frac{c_{Xi}(\varepsilon - 1)}{\varepsilon} \tag{2.17}$$

Second, free entry and exit ensures:

$$a_{Soi}w_{Si} + a_{Koi}r_i \geq \frac{c_{Zi}(\theta - 1)}{\theta} \sum_{j=1}^{3} z_{ij}$$

$$a_{Sni}w_{Si} + a_{Kni}r_i \geq \frac{c_{Xi}(\varepsilon - 1)}{\varepsilon} \sum_{j=1}^{3} x_{ij}$$

$$a_{Smi}w_{Si} + a_{Kmi}\left[3 + \sum_{i \neq j} \gamma_{ij}\right] r_i \geq \sum_{j=1}^{3} \frac{c_{Xj}(\varepsilon - 1)}{\varepsilon} x_{jj}$$

$$a_{Smi}w_{Si} + a_{Kmi}[2 + \gamma_{ij}]r_i \geq \frac{c_{Xi}(\varepsilon - 1)}{\varepsilon} x_{ii} + \frac{c_{Xj}(\varepsilon - 1)}{\varepsilon} x_{jj}$$

$$a_{Smi}w_{Si} + a_{Kmi}[1 + \gamma_{ij}]r_i \geq \frac{c_{Xj}(\varepsilon - 1)}{\varepsilon} \sum_{k=1}^{3} x_{jk}$$

(2.18a)–(2.18c)

3.6 *Factor-endowment and current-account-balance constraints*

We assume that, in equilibrium, all factors are fully employed and that every country maintains multilateral (though not bilateral) current account balance; endogenous bilateral current account imbalances allow for endogenous bilateral FDI of physical capital. Following the established literature, this is a static model. The formal factor-endowment and multilateral current-account-balance constraints are provided in the Appendix.

4 Calibration of the model

The complexity of the model, including the complementary-slackness conditions shown, introduces a high degree of non-linearity, and it cannot be solved analytically. Consequently, we provide numerical solutions to the model, as in Markusen (2002) and related studies. In order to address interesting issues, we can potentially employ our three-country model to distinguish among four different scenarios: (i) bilateral trade and FDI flows between two developed economies, or intra-DC flows (with a less developed third country or LDC); (ii) bilateral flows from a DC to an LDC (with a developed third country); (iii) bilateral flows from an LDC to a DC (with a developed third country); and (iv) bilateral flows from an LDC to another LDC, or intra-LDC flows (with a developed third country). A key consideration is that – due to the non-linearities of the model – the *marginal* effects of bilateral economic sizes, relative factor endowment differences, and transaction costs on bilateral trade and investment flows will differ depending upon the economic characteristics of the *ROW*. As the stylized facts in Section 2 suggest though, we focus on intra-DC (or OECD) flows, reserving analysis of DC-LDC flows and intra-LDC flows for future work. We use *GAMS* for our numerical analysis.

4.1 Exogenous variables

Our intent is to keep as close to the spirit of modern GE models of multinational firms as possible. In this regard, we note the following assumptions made about the exogenous variables in our model.[16]

For analytical purposes, the relative size of endowments among the three countries matters. We assume a world endowment of capital (K) of 240 units, skilled labor (S) of 90 units, and unskilled labor (U) of 100 units. In our case studying intra-DC trade, *ROW* represents the developing world. Since our focus will be on estimating gravity equations using primarily OECD data, it makes sense to treat the *ROW* as the developing world. Initially, we set country i's (j's) relative shares of the world endowments of physical capital and skilled labor at 1/3 (1/3) and *ROW*'s at 1/3 (as in Bergstrand and Egger 2007), and country i's (j's) share of unskilled labor at 1/4 (1/4) and *ROW*'s at 1/2 (to make *ROW* a developing country). Hence, both DCs are capital- and skilled-labor abundant relative to *ROW*. While initially i and j have the same GDPs as *ROW*, our simulations will show that our theoretical relationships hold for a wide choice of relative economic sizes (that match the distribution of GDPs for OECD countries), so that the choice of initial endowments is not limiting.

We appealed to actual trade data to choose initial values for transport costs (rather than choosing values arbitrarily as in the literature). Using the United Nations' (UN's) COMTRADE data, we aggregated bilateral five-digit Standard International Trade Classification (SITC) trade flows into aggregate bilateral *intermediate goods* and aggregate bilateral *final goods* trade flows, according to the UN's *Classification by Broad Economic Categories* (2003). Using the bilateral trade data for weights, we calculated the mean final goods and intermediate goods bilateral transport cost factors [(cif – fob)/fob] for intra-DC trade, intra-LDC trade, and trade between DCs and LDCs. For final goods (differentiated or homogeneous), the transport cost factor was 7.6 per cent for intra-DC trade, 19.2 per cent for intra-LDC trade, 20.2 per cent for trade flows

[16] It is common in the GE literature to denote trade costs, investment costs, and factor endowments as "parameters." We term these "exogenous variables" here.

from DCs to LDCs, and 20.2 per cent for flows from LDCs to DCs. For intermediate goods, the transport cost factor was 9.8 per cent for intra-DC trade, 21.2 per cent for intra-LDC trade, 20.0 per cent for trade flows from DCs to LDCs, and 20.1 per cent for flows from LDCs to DCs.

We constructed initial values for tariff rates using Jon Haveman's TRAINS data for the 1990s. Tariff rates are available at the Harmonized System eight-digit level. Using the UN's *Classification by Broad Economic Categories* again, we classified tariff rates by final and intermediate goods five-digit SITC categories. We then weighted each country's five-digit SITC tariff to generate average tariffs at the country level for each year 1990–2000. Tariff rates were then weighted by aggregate bilateral final goods or intermediate goods imports to obtain mean regional tariff rates, accounting for free trade agreements and customs unions. For final goods, the tariff rate was 1.1 per cent for intra-DC trade, 9.3 per cent for intra-LDC trade, 9.7 per cent for trade from DCs to LDCs, and 4.0 per cent for trade from LDCs to DCs. For intermediate goods, the tariff rate was 0.2 per cent for intra-DC trade, 6.2 per cent for intra-LDC trade, 6.1 per cent for trade from DCs to LDCs, and 0.6 per cent for trade from LDCs to DCs.

Data on bilateral costs of investment (say, informational costs) and on policy barriers to FDI are not available. Carr *et al.* (2001) used a country "rating" score from the World Economic Forum's *World Competitiveness Report* that ranges from 0 to 100. However, ad valorem equivalent measures are not available across countries, much less over time. Consequently, we assumed values to represent informational costs and policy barriers to FDI between countries. We assumed initially a tax-rate equivalent (for γ) of 90 per cent for intra-DC FDI, 120 per cent for FDI flows from LDCs to DCs, and 140 per cent for FDI flows from DCs to LDCs, but results are robust to alternative values. While these choices are somewhat arbitrary, they seem feasible in the context of recent estimates of analogous "trade costs" in Anderson and van Wincoop (2004) of 170 per cent.

4.2 *Other parameter values*

We now discuss other parameter values assigned initially. Consider first the utility function. In equation (2.1), the only two parameters are the Cobb–Douglas share of income spent on final differentiated products from various producers (η) and the CES parameter (ε) influencing the elasticity of substitution between final differentiated products ($\sigma \equiv 1-\varepsilon$). Initially, we use 0.71 for the value of η. This is based upon an estimated share of manufactures trade in overall world trade averaged between

1990 and 2000 using five-digit SITC data from the UN's COMTRADE dataset; this is a plausible estimate of the importance of differentiated products in overall utility of developed countries. The initial value of ε is set at -5, implying an elasticity of substitution of 6 among differentiated final goods. This value is consistent with a wide range of recent cross-sectional empirical studies estimating this elasticity between 2 and 10, see Feenstra (1994); Baier and Bergstrand (2001); Head and Ries (2001); Eaton and Kortum (2002); and Hanson (2005).

Consider next production function (2.7) for final differentiated goods. Labor *and* intermediates share of final differentiated goods gross output is assumed to be 0.8, which is conventional; the Cobb–Douglas formulation implies the elasticity of substitution between capital and labor is unity. In one of a series of papers, Griliches (1969) proposed – in a three-factor world with unskilled labor, skilled labor, and physical capital – that skills (or human/knowledge capital) were more complementary with physical capital than with unskilled labor.[17] Griliches found convincing econometric evidence that physical capital and skilled labor were relatively more complementary in production than physical capital and unskilled labor. Most evidence to date suggests that skills and physical capital are relatively complementary in production. In (to our knowledge) the only empirical study of MNE behavior considering this issue, Slaughter (2000) finds statistically significant evidence in favor of capital-skill complementarity. Initially, we assume $\chi = -0.25$, implying an elasticity of substitution of 0.8 and complementarity between physical and human capital.

Regarding unskilled labor and intermediates, the national debate on outsourcing among industrialized economies is basically concerned with the substitution of intermediate goods produced in relatively unskilled-labor-abundant economies (with some final processing at home) for immobile unskilled labor at home. To capture this substitutability, we allow $0 < \delta < 1$; specifically, we assume an elasticity of substitution of 1.2 ($\delta = 0.167$).

We assume initially that intermediate products are better substitutes for each other in production than final goods are substitutes in consumption and choose an intermediates elasticity of substitution of 8 ($\theta = -7$) in equation (2.8). Results are robust to alternative values.

Production of intermediates uses skilled and unskilled labor. We assume this production is Cobb–Douglas, and that the cost share of skilled labor in production (β) is 0.1 in equation (2.8).[18]

17 In fact, human and physical capital may even be absolute complements, rather than just more complementary.

18 The choice of 0.1 was somewhat arbitrary. Empirical evidence suggests that human capital's share of final goods production is approximately one-third. We know less about

As in the 2 × 2 × 2 Knowledge-Capital model in Carr *et al.* (2001), a firm (or headquarters) setup uses only skilled labor. For national intermediates and final goods producers, we assume the headquarters setup requires a unit of skilled labor per unit of output ($a_{So1} = a_{So2} = a_{So3} = a_{Sn1} = a_{Sn2} = a_{Sn3} = 1$). As in the Knowledge-Capital model, we assume "jointness" for multinational firms; that is, services of knowledge-based assets are joint inputs into multiple plants. Markusen suggests that the ratio of fixed headquarters setup requirements for a (two-plant) horizontal or (one-plant) vertical multinational relative to a domestic firm ranges from one to two. We assume initially a ratio of 1.01 ($a_{Sh1} = a_{Sh2} = a_{Sh3} = a_{Sv1} = a_{Sv2} = a_{Sv3} = 1.01$). Hence, to bias the theoretical results initially *in favor of multinational activity* (that is, in favor of MNEs completely displacing trade), we assume the additional firm setup cost of an MNE over a national firm is quite small. We assume that every plant (national or MNE) requires one unit of home physical capital ($a_K = 1$). However, an MNE setting up a plant abroad can face an additional fixed investment cost (γ), values of which were specified earlier.

5 A theoretical rationale for gravity equations of FDI, final goods trade, and intermediates trade

We use our numerical general equilibrium model to motivate a theoretical rationale for identifying the main economic determinants of bilateral intermediate goods trade – in a manner consistent with identifying the main economic determinants of bilateral FDI and bilateral final goods trade – using gravity equations. The two critical factors in the gravity equation explaining flows are GDPs and "frictions." We address each in turn.

5.1 *Economic size and similarity*

We discuss first the expected relationships between exporter (home) and importer (host) GDPs and the three types of flows suggested by our theory. However, we must first show two key features of the gravity equation. First, in a simple theoretical world of N (>2) countries, one final differentiated good, no trade costs, but internationally immobile factors (e.g. labor and/or capital), we know from the international trade gravity-equation literature that the trade flow from country *i* to country *j* in year

intermediates. However, we conjecture that skills are even less important in intermediates production. The results in the remainder of the paper are robust to changing this value.

t ($Flow_{ijt}$) will be determined by:

$$Flow_{ijt} = GDP_{it}GDP_{jt}/GDP_t^W \tag{2.19}$$

where GDP^W is world GDP, or in log-linear form:

$$\ln Flow_{ijt} = -\ln(GDP_t^W) + \ln(GDP_{it}) + \ln(GDP_{jt}) \tag{2.20}$$

However, the standard frictionless trade gravity equation can be altered algebraically to separate influences of economic size ($GDP_i + GDP_j$) and similarity (s_is_j), where $s_i = GDP_i/(GDP_i + GDP_j)$ and analogously for j:

$$\begin{aligned} Flow_{ijt} &= GDP_{it}GDP_{jt}/GDP_t^W \\ &= (GDP_{it} + GDP_{jt})^2(s_{it}s_{jt})/GDP_t^W \end{aligned} \tag{2.21}$$

When countries i and j are identical in economic size ($s_i = s_j = 1/2$), s_is_j is at a maximum. In log-linear form, (2.21) is:

$$\ln Flow_{ij} = -\ln(GDP^W) + 2\ln(GDP_i + GDP_j) + \ln(s_is_j) \tag{2.22}$$

Second, while the gravity equation is familiar in algebraic form, it will be useful to *visualize* the frictionless "gravity" relationship. Figure 2.1a illustrates the gravity-equation relationship between bilateral trade flows, GDP size, and GDP similarity summarized in equation (2.21) for an arbitrary hypothetical set of country GDPs (N > 2). First, we explain the figure's axes and labeling. The lines on the y axis in the bottom plane range from 1 to 2.2. The y axis indexes the joint economic size of countries i and j; line 1 denotes the smallest combination of GDPs and line 2.2 denotes the largest combination. The GDP values are scaled to this index with the range tied to our *World Development Indicators* dataset on GDPs. The x axis is indexed from 0 to 1. Each line represents i's share of both countries' GDPs; the *center line* represents 50 per cent, or *identical GDP shares for i and j*. The z axis measures the "flow" from i to j as determined by equation (2.21), which is a simple algebraic transformation of typical (frictionless) gravity equation (2.19). Figure 2.1a illustrates the relationships between country economic size (measured by sum of GDPs of i and j) on the y axis, GDP similarity on the x axis, and the "flow" from i to j as determined by simple frictionless gravity equation (2.21).

Common to Knowledge-Capital-type theoretical GE models, analytic solutions are unobtainable and we rely on numerical solutions to the GE model to obtain "theoretical" relationships, using figures generated by the

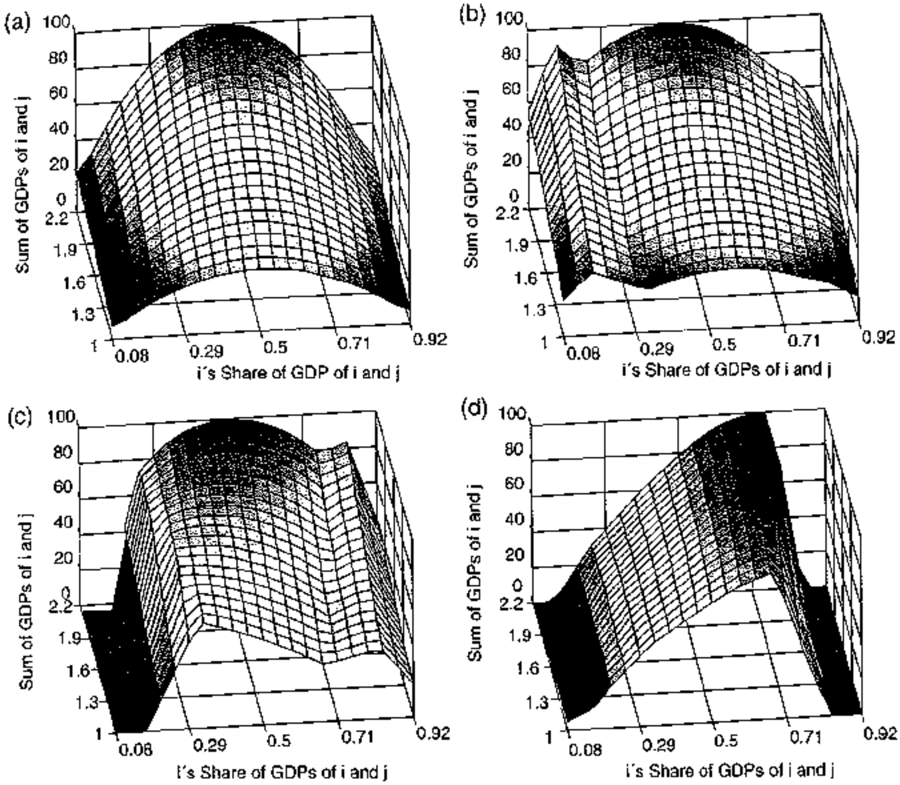

Figure 2.1. Theoretical flows of final goods and intermediate goods nominal exports and nominal outward FDI; (a) Gravity-equation flow from i to j; (b) Final goods nominal exports from i to j; (c) Intermediate goods nominal exports from i to j; (d) Nominal FDI from i to j.

numerical GE version of our model, as in Markusen (2002), Braconier *et al.* (2005), and Bergstrand and Egger (2007). We can now focus on the bilateral relationships between two economies with identical bilateral relative factor endowments and transaction cost levels. That is, we can examine using the numerical model the relationships between economic size (sum of GDPs of i and j) and GDP similarity with bilateral final goods exports from i to j (X_{ij}), bilateral intermediate goods exports from i to j (Z_{ij}), and the bilateral foreign direct investment flow from i to j (FDI_{ij}), shown in Figures 2.1b, 2.1c, and 2.1d, respectively.[19]

[19] Gross bilateral FDI from i to j is for HMNEs in industry X, since relative factor endowments are equal between i and j and unchanged.

5.1.1 Proposition 1 First, we note in Figures 2.1b–2.1d that (gross) bilateral final goods trade, intermediate goods trade, and FDI from i to j, respectively, are all positive monotonic functions of the *size* of the two countries' GDPs, as the gravity equation suggests for a given GDP_{ROW} (see Figure 2.1a). For any given share of i in i's and j's total GDP, an increase in the absolute endowments of both countries increases their bilateral final goods trade, bilateral intermediate goods trade, and FDI flow. The numbers of NEs and HMNEs increase monotonically with a larger joint economic size (sum of GDPs of i and j); figures are omitted for brevity, but are available on request. More resources cover more setup costs of final and intermediate goods NEs and of HMNEs; economies of scale and love of variety for consumers and intermediates specialization for producers expand the number of total varieties produced for all three countries by both types of firms in i. This is testable *Proposition 1*.

5.1.2 Proposition 2 Second, we note that final goods, intermediate goods, and FDI flows from i to j are all positively related to the *similarity* of economic sizes. This is testable *Proposition 2*. With the exception of FDI, final goods and intermediate goods trade flows from i to j are maximized when countries i and j are identically sized; this is a traditional feature of the gravity equation. In the case of FDI, the flow from i to j is maximized when i is slightly larger than j; this subtle feature of FDI will be addressed shortly below. Thus, the surfaces suggest that (using aggregate bilateral final goods, intermediates, and FDI flows) the flows are all *complements*, even though final goods trade and FDI are inherently substitutes. What explains this?

The intuition can be seen by starting at the far right-hand side (RHS) of Figures 2.1b–2.1d, when j's GDP is small relative to i's. When j's GDP share becomes positive (via an exogenous reallocation of initial factor endowments from i to j), j's relatively small (final) consumer market is most profitably served by exports from national final goods firms in i and some domestic production in j. In contrast to Bergstrand and Egger (2007) which had no intermediates, intermediates trade from i to j also increases as domestic production in j uses differentiated intermediates from home and foreign producers. As i's (j's) share of their combined GDPs gets smaller (larger), the number of exporters and varieties in i and overall demand in j expand (figures not shown), such that exports from i to j of final and intermediate goods increase.

At some point (around 0.75 on the x axis), as i's (j's) GDP share gets even smaller (larger), it becomes more profitable for i to serve j's market using HMNEs based in i; hence, FDI from i to j increases. Since the number of HMNEs increases, the demand for intermediates increases. While in the Markusen $2 \times 2 \times 2$ KC model, the increase in HMNEs would eventually *completely displace* national final goods exporters in *i*, the increase in multi-plant HMNEs in our model leads to a fall in the relative demand and price of skilled labor and a rise in the relative demand and price of physical capital in *i*; figures are not shown for brevity, but are available on request. These relative factor price changes in *i* curb the creation of HMNEs in *i* as *i*'s GDP share gets smaller and curb the displacement of final goods national exporting firms in *i*, such that national final goods exports in *i*, national intermediate goods exports, and HMNEs based in *i* with production in *j* can all coexist as the GDPs of countries *i* and *j* become identical.[20]

5.1.3 Proposition 3 Overall, Figures 2.1b–2.1d suggest a theoretical rationale for explaining gross bilateral final goods trade, intermediates trade, and FDI flows from *i* to *j* in terms of the product of GDPs of *i* and *j* (or size and similarity). However, a third *subtler* issue is that the gross FDI flow from *i* to *j* is *not* maximized when *i* and *j* are identically sized. Rather, the theoretical model suggests that FDI from *i* to *j* should be maximized when *i*'s share is larger than *j*'s. This is consistent intuitively with the notion that profit-maximizing firms in *i* will want to serve the relatively small market *j* using HMNEs rather than exports, once *j* crosses a minimum market-size threshold. This is testable *Proposition 3*.

5.2 *Trade and investment costs*

While gravity equations typically include bilateral distance and several dummy variables to reflect trade and investment frictions, our theoretical

[20] The small temporary dip in intermediates exports from *i* to *j* as *j*'s GDP share increases toward 1/2 in Figure 2.1c is easily explained, and demonstrates the richness of the model's interactions. First, we note that intermediate goods exports *from j to i* (not shown for brevity) is the mirror image of Figure 2.1c, where consequently the "wrinkle" would occur at *i*'s GDP share of 0.16–0.24, as in Figure 2.1b for final goods exports from *i* to *j*. Start initially when *i*'s GDP share is small. When *i*'s share of the two countries' endowments increases beyond 0.16 (0.16–0.24, or third column of the x axis), the relative economic size of *i* crosses the threshold where a large number of *vertical* MNEs based in *i* with plants in (relatively unskilled-labor-abundant) *ROW* surface (beyond the less dramatic increase in HMNEs of *i* in *j* and *ROW*). This causes a physical capital outflow from *i* to *ROW*, reducing capital available for national final goods exporters in *i* to exist profitably (and hence, the "wrinkle" at *i*'s GDP share of 0.16–0.24 in Figure 2.1b for final goods exports from *i* to *j*). Consequently, with fewer final goods exports from *i* to *j*, demand for intermediate goods exports from *j* to *i* falls; this explains the "wrinkle" for intermediate goods exports from *j* to *i* at *i*'s GDP share of 0.16–0.24 (not shown), and analogously the (mirror) "wrinkle" for intermediate goods exports from *i* to *j* at *i*'s GDP share of 0.76–0.84 (shown in Figure 2.1c). In a robustness analysis, this "wrinkle" dissipates as *ROW*'s share of unskilled labor converges to those of countries *i* and *j*.

model includes bilateral iceberg-type final goods trade costs, intermediate goods trade costs, and investment costs (FDI barriers). Moreover, as discussed earlier, we have time-varying empirical measures of all three variables, allowing some testable propositions.

5.2.1 Proposition 4 For all types of flows, the own-price effect should be negative. Final goods trade from i to j should be a negative function of natural (such as transport) final goods trade costs between i and j. Intermediate goods trade from i to j should be a negative function of intermediate goods trade costs between i and j. FDI from i to j should be a negative function of FDI barriers between i and j. These effects are straightforward and figures (omitted for brevity) confirm these conjectures. These three predictions form testable *Proposition 4*.

5.2.2 Proposition 5 Regarding cross-price effects, in most cases economically conflicting effects are potentially at play; however, there is one unambiguous prediction. An increase in the barrier to FDI (final goods trade cost) from i to j should be positively related to final goods exports (FDI) from i to j. These relationships are expected since horizontal FDI and final goods trade are gross substitutes (with respect to prices).[21] This forms testable *Proposition 5*.

The remaining cross-price effects are ambiguous. Consider for instance the effect of intermediate goods trade costs on final goods. An increase in intermediate goods trade costs from i to j will tend to increase the cost and price of final good exports, tending to reduce final goods exports from i to j. However, in general equilibrium a rise in intermediate trade costs, by reducing demand for intermediate goods and factors of production, makes production of final goods more competitive, potentially increasing final goods exports from i to j.

Consider next the cross-price effects of final goods trade costs on intermediate goods trade from i to j. An increase in final goods trade costs between i to j should reduce demand for final goods exports from i to j and j to i, reducing demand for intermediate products from j to i and i to j; intermediates trade from i to j could decline. However, the change in relative prices could make intermediate goods production more competitive, potentially increasing intermediates trade from i to j.

Similar ambiguities arise for the cross-price effects on FDI from i to j. However, for brevity, discussion of these effects is omitted. Finally, the

21 Regarding vertical trade, an increase in this FDI barrier would tend to reduce final goods exports from j to i, but not i to j.

model was calibrated for a wide range of alternative values of parameters; the theoretical surfaces were qualitatively the same for a wide choice of values.

6 Estimation of gravity equations for final goods, intermediate goods, and FDI flows

In this section, we evaluate empirically the five "testable" propositions identified in Section 5. In Section 6.1, we describe the dataset we used to estimate the relationships and the other RHS variables we included to avoid specification error. Note, of course, that the theoretical figures generated by our numerical CGE model in Section 5 implicitly *hold constant* all other factors influencing trade and FDI, notably the usual costs of trade and investment associated with frictions such as distance and language. In Section 6.2, we provide the empirical results and evaluate the testable propositions. Section 6.3 provides a summary of an analysis for robustness of the results.

6.1 *Specifications and data*

To evaluate these five testable propositions, we run typical log-linear gravity equations using pooled cross-section time series data for the period 1990–2000. We specify traditional gravity equations for the log of the gross flow from i to j for either final goods trade, intermediate goods trade, or FDI on the LHS. The RHS variables can be decomposed into three groups. The first group is the log of the exporter GDP and log of the importer GDP. The second group includes explicit time-varying measures of logs of final goods trade costs (bilateral cif-fob factors for final goods trade), intermediate goods trade costs (bilateral cif-fob factors for intermediate goods trade), and a measure of the costs of FDI (to be described below). The third group includes traditional bilateral "friction" variables (controls): log of bilateral distance between economic centers, a dummy variable for adjacency (sharing a common land border), and a dummy for sharing a common language.

We now summarize the data used. The trade flow data were described earlier in Section 2. The outward FDI (stock) data were constructed from UNCTAD data (country profiles). GDP data are from the World Bank's *World Development Indicators*. Bilateral distances are from the CEPII database in France. The adjacency and language dummies were compiled using the CIA *World Factbook*. Time-varying final goods and intermediate goods bilateral cif-fob factors were computed using import and export data from our trade flow dataset. The time-varying investment cost index is that used in Carr *et al.* (2001), Markusen (2002), and Markusen and Maskus (2001, 2002), and was kindly provided by Keith Maskus.

It is important to emphasize that the theoretical surfaces describing the relationships between trade and FDI flows from *i* to *j* are based upon the results of a numerical model where countries *i* and *j* are initially *identical* in all respects (and *ROW* is a developing economy, representing a group of developing economies). Consequently, the three theoretical propositions relating flows from *i* to *j* to the two countries' economic sizes and economic similarities are based upon two developed countries' GDPs, *assuming* the two countries' relative factor endowments are identical and unchanging. Consequently, while we computed final and intermediates trade flows among 160 countries, we would only expect the testable propositions to hold for a group of *similar, advanced economies,* such as members of the OECD. Consequently, in our basic results we examine only trade and FID flows among all twenty-four member countries of the OECD (in 1990, there were only twenty-four members). We will, however, provide some results in the sensitivity analysis for trade and FDI flows with and among non-OECD countries, noting that we have no prior expectations for such flows (the analysis of which is beyond the scope of this already lengthy chapter and the subject of future research).

6.2 Empirical results

Table 2.3 reports the gravity-equation estimates for the three types of flows among OECD countries. We discuss the results for this table in the order above for *Propositions 1–5.*

First, we report the GDP elasticities for the exporter (home) and importer (host) countries. The coefficient estimates for GDPs are positively signed and are statistically significant. These elasticity estimates confirm *Proposition 1* that bilateral final goods trade, intermediate goods trade, and FDI flows are positively related to the economic size of the two countries.

Second, in light of the discussion at the beginning of Section 5, the similarly sized GDP coefficient estimates for exporter and importer countries tend to confirm the second proposition as well; final goods and intermediate goods trade flows are increasing in similarity of economic size. However, for the two trade flows in Table 2.3, the coefficient estimate for exporter GDP is slightly larger than that for importer GDP. Yet theoretical Figures 2.1b and 2.1c suggested that the gross trade (FDI) flows should be maximized when the two countries are identically sized (when *i* is larger than *j*). To provide further confirmation of *Proposition 2,* we illustrate in Figure 2.2 the predicted values from all three regressions reported

Table 2.3. *Bilateral flows of final and intermediate goods exports and bilateral stocks of outward FDI within the OECD (1990–2000)*

	Dependent variable is log of:					
	Final goods exports$_{ijt}$		Intermediate goods exports$_{ijt}$		Outward FDI stocks$_{ijt}$	
Log GDP$_{it}$	0.835	0.025[b]	0.952	0.031[b]	1.164	0.044[b]
Log GDP$_{jt}$	0.794	0.027[b]	0.799	0.031[b]	0.809	0.062[b]
Log final goods trade costs$_{ijt}$	−0.785	0.148[b]	−0.196	0.119	−0.237	0.254
Log intermediate goods trade costs$_{ijt}$	−0.124	0.089	−0.849	0.104[b]	−0.425	0.179[a]
Log investment costs$_{jt}$	0.025	0.111	−0.021	0.137	−0.621	0.261[a]
Other control variables:						
Log distance$_{ij}$	−0.719	0.037[b]	−0.958	0.044[b]	−0.826	0.084[b]
Adjacency$_{ij}$	0.166	0.141	−0.056	0.150	−0.665	0.314[a]
Language$_{ij}$	0.510	0.122[b]	0.789	0.120[b]	1.955	0.232[b]
Time dummies	yes		yes		yes	
Number of observations	5,328		5,328		2,731	
R^2	0.850		0.815		0.660	
Root MSE	0.799		1.040		1.630	

Notes: Reported coefficients and standard errors are pooled OLS estimates. Standard errors are robust to heteroskedasticity and clustering at the country-pair level. Superscripts a and b refer to significance levels of 5% and 1%, respectively.

in Table 2.3. In particular, Figures 2.2a and 2.2b provide the *predicted* empirical final goods and intermediate goods trade flows, respectively, based upon the regression equations. Figures 2.2a and 2.2b are strikingly similar to the corresponding predicted *theoretical* trade flows generated by the numerical version of our general equilibrium model, where the data for GDP size and similarity are based upon our empirical distributions using actual GDP data (Figures 2.1b and 2.1c). In Figures 2.2a and 2.2b (predicted empirical) final goods and intermediate goods trade flows are indeed maximized when the two countries are identically sized.

Third, Table 2.3 reveals that the *difference* in the home and host countries' GDP coefficient estimates for FDI from i to j is the largest of the three regressions. A larger elasticity estimate for the home country's GDP compared to that of the host country's GDP implies that the FDI flow should be maximized when i's share of the two countries' GDP is larger. Figure 2.2c confirms using the predicted empirical values of FDI flows based upon the regression equation that FDI from i to j is indeed

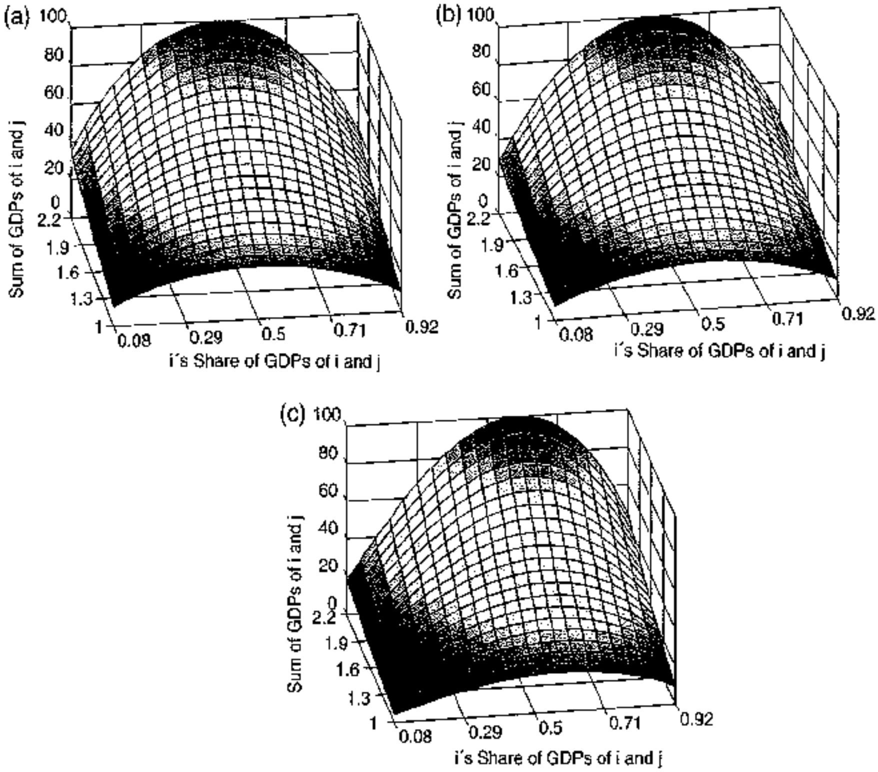

Figure 2.2. Empirical (intra-OECD) flows of final goods and intermediate goods nominal exports and nominal outward FDI; (a) Intra-OECD final goods nominal exports from i to j; (b) Intra-OECD intermediate goods nominal exports from i to j; (c) Intra-OECD FDI from i to j.

maximized when i's GDP share is *larger* than j's share. This confirms *Proposition 3*, and is consistent with Figure 2.1d in the theory that FDI is maximized when i's share is larger.

Fourth, the third, fourth and fifth rows of Table 2.3 provide the coefficient estimates for the *own-price* effects of bilateral final goods trade costs, bilateral intermediate goods trade costs, and (multilateral) investment costs, respectively (no measure of *bilateral* investment costs is available). *Proposition 4* stated that the own price effects should all be negative. The results for the own-price effects in Table 2.3 confirm this proposition robustly. For final goods exports, final goods trade costs have an economically and statistically significant negative effect on such trade. Intermediate goods trade costs from i to j have an economically and statistically significant negative effect on intermediate goods exports from *i* to *j* as expected. Also, the investment cost index has an economically and statistically significant negative effect on outward FDI from *i* to *j*. *Proposition 4* is confirmed with strong statistical support.

Fifth, the only testable proposition for *cross-price* effects was an expected positive coefficient estimate for the effect of investment (final goods trade) costs on final goods trade (FDI). *Proposition 5* is confirmed only for investment costs' effect on final goods trade, and that coefficient estimate is neither economically nor statistically significant.

Finally, we note that the coefficient estimates for standard control variables for trade and investment "frictions" – bilateral distance, adjacency dummy, and language dummy – generally accord with earlier studies, even though our theoretical model is agnostic on these variables (as in Markusen 2002), and the R^2 values are in line with these studies. The negative coefficient estimates for bilateral distance are in line with previous estimates and are statistically significant. The coefficient estimate for the adjacency dummy has the typical sign for final goods, but is statistically insignificant. Since no previous studies have used the gravity model for intermediate goods trade flows, there is no expectation for this regression; the coefficient estimate is negative, but economically and statistically insignificant. The negative and statistically significant coefficient estimate for adjacency for FDI is plausible because adjacent markets are more likely to be served by trade rather than horizontal FDI. Finally, the coefficient estimates for the language dummy in each regression have plausible signs and are economically and statistically significant.

6.3 Robustness analysis

We have conducted numerous robustness analyses. For brevity, we report only three to confirm that our results are robust. First, because outward FDI stocks often are zero, the results provided in Table 2.3 for FDI exclude zeroes. Santos Silva and Tenreyro (2006) showed that a Poisson quasi-maximum likelihood (PQML) estimator may avoid the bias associated with heteroskedasticity associated with Jensen's inequality. Moreover, the technique also allows a natural way for including zeroes on the LHS, a problem for the FDI variable as noted. Table 2.4 provides the results from re-estimating all three models in Table 2.3 using the PQML estimator instead; note that the inclusion of zeroes has enlarged the FDI sample. The results for all the variables' coefficient estimates are robust to this alternative estimation procedure, with adjacency now having a statistically significant effect on intermediates.

Second, the bilateral trade- and investment-cost variables included may not represent all such potential costs. Gravity-equation analyses have

Table 2.4. *Sensitivity analysis I: Poisson quasi-maximum likelihood estimation of bilateral flows of final and intermediate goods exports and bilateral stocks of outward FDI within the OECD (1990–2000)*

	Dependent variable is log of:					
	Final goods exports$_{ijt}$		Intermediate goods exports$_{ijt}$		Outward FDI stocks$_{ijt}$	
Log GDP$_{it}$	0.783	0.038^c	0.801	0.033^c	0.870	0.052^c
Log GDP$_{jt}$	0.803	0.046^c	0.786	0.042^c	0.750	0.042^c
Log final goods trade costs$_{ijt}$	−0.707	0.165^c	−0.359	0.159^b	−0.243	0.356
Log intermediate goods trade costs$_{ijt}$	−0.211	0.146	−0.638	0.111^c	−0.798	0.231^c
Log investment costs$_{jt}$	−0.063	0.133	0.092	0.135	−0.510	0.196^c
Other control variables:						
Log distance$_{ij}$	−0.578	0.049^c	−0.627	0.049^c	−0.535	0.079^c
Adjacency$_{ij}$	0.244	0.113^b	0.292	0.112^c	−0.989	0.213^c
Language$_{ij}$	0.336	0.101^c	0.461	0.092^c	1.318	0.132^c
Time dummies	yes		yes		yes	
Number of observations	5,328		5,328		3,439	
Log pseudo-likelihood	−1786.68		−1432.95		−6091.52	

Notes: Reported coefficients and standard errors are pooled Poisson QMLE estimates. Standard errors are robust to heteroskedasticity and clustering at the country-pair level. Superscripts a, b, and c refer to significance levels of 10%, 5%, and 1%, respectively.

often replaced specific bilateral variables with country-pair fixed effects. Table 2.5 presents the results of applying country-pair-specific (ij) fixed effects, which eliminates the "Other control variables" in Table 2.3. We note that once again our coefficient estimates are robust to using country-pair fixed effects, with the exception that FDI's coefficient estimate for investment costs becomes statistically insignificant.

Third, we were curious to see how well the gravity equation for intermediates trade (as well as for final goods trade and FDI) held up for a sample of countries *outside* the OECD. One might expect that the gravity equation (and Ethier-type intermediates trade) would not explain the variation in developing countries' intermediates trade that well. Interestingly, the gravity equation works well also for the sample of non-OECD countries; see Table 2.6. Not surprisingly, the R^2 values are all lower than those for the OECD countries in Table 2.3. For intermediates trade, the R^2 is only 11 per cent less than for the OECD countries. Also, the coefficient estimates are similar. And where they differ, it can be explained

Table 2.5. *Sensitivity analysis II: fixed country-pair effect estimates of bilateral flows of final and intermediate goods exports and bilateral stocks of outward FDI within the OECD (1990–2000)*

	Dependent variable is log of:					
	Final goods exports$_{ijt}$		Intermediate goods exports$_{ijt}$		Outward FDI stocks$_{ijt}$	
Log GDP$_{it}$	0.125	0.042	0.170	0.096	0.307	0.171
Log GDP$_{jt}$	0.809	0.043	0.571	0.096	0.609	0.146
Log final goods trade costs$_{ijt}$	−0.474	0.018	0.034	0.041	−0.107	0.070
Log intermediate goods trade costs$_{ijt}$	0.013	0.014	−0.732	0.031	−0.171	0.059
Log investment costs$_{jt}$	0.004	0.036	−0.085	0.080	−0.088	0.116
Other control variables:						
Time dummies	yes		yes		yes	
Number of observations	5,328		5,328		2,731	
Within R^2	0.460		0.201		0.307	
Root MSE	0.258		0.583		0.566	

Notes: Reported coefficients and standard errors are pooled OLS estimates. Standard errors are robust to heteroskedasticity and clustering at the country-pair level. Superscripts a, b, and c refer to significance levels of 10%, 5%, and 1%, respectively.

readily. For instance, in Table 2.3 the coefficient estimate for adjacency was negative (positive) and statistically significant (insignificant) for outward FDI (final goods trade). These signs are consistent with HMNEs and final goods trade for developed countries; adjacent countries should trade final goods more and have less horizontal FDI, because relative trade costs are low. However, for developing countries, if MNEs are vertical, then adjacency's positive and statistically significant coefficient estimate in the FDI equation is theoretically justified in Table 2.6, as adjacency lowers relative trade costs which are important for national firms *and* VMNEs (which export final goods).

7 Conclusions

We note three potential contributions of our study. First, we have constructed from five-digit SITC bilateral trade flows among 160 countries the most comprehensive bilateral trade flow dataset decomposed into *final* goods and *intermediate* goods trade flows. Second, developing a Knowledge-and-Physical-Capital model of multinationals including a

Table 2.6. *Sensitivity analysis III: bilateral flows of final and intermediate goods exports and bilateral stocks of outward FDI outside the OECD (1990–2000)*

	Dependent variable is log of:					
	Final goods $exports_{ijt}$		Intermediate goods $exports_{ijt}$		Outward FDI $stocks_{ijt}$	
Log GDP_{it}	1.143	0.015	1.392	0.016	1.403	0.083
Log GDP_{jt}	0.984	0.022	0.855	0.025	0.384	0.125
Log final goods trade $costs_{ijt}$	−0.650	0.018	−0.116	0.019	0.342	0.203
Log intermediate goods trade $costs_{ijt}$	−0.040	0.015	−0.699	0.017	0.644	0.206
Log investment $costs_{jt}$	−0.735	0.074	−0.072	0.084	−0.714	0.304
Other control variables:						
Log $distance_{ij}$	−0.831	0.033	−1.083	0.037	0.311	0.181
$Adjacency_{ij}$	0.937	0.179	0.784	0.183	1.156	0.421
$Language_{ij}$	0.931	0.077	1.031	0.094	1.081	0.403
Time dummies	yes		yes		yes	
Number of observations	22,103		22,103		1,686	
R^2	0.678		0.708		0.513	
Root MSE	1,649		1,810		1,898	

Notes: Reported coefficients and standard errors are pooled OLS estimates. Standard errors are robust to heteroskedasticity and clustering at the country-pair level. Superscripts a, b, and c refer to significance levels of 10%, 5%, and 1%, respectively.

second production stage (intermediates) and calibrating it numerically, we formulated a theoretical rationale for estimating (simultaneously) *gravity equations* for bilateral final goods trade flows, bilateral intermediate goods trade flows, and bilateral outward FDI flows. Third, we showed that the predicted theoretical final goods trade, intermediate goods trade, and FDI flows from i to j from the model explained very well empirical final goods trade, intermediate goods trade, and FDI flows from i to j. As Markusen's introductory quote suggests, Ethier's (1982) intermediate-inputs approach is empirically "very relevant" and goes a long way to explain the actual pattern of bilateral intermediates *outsourcing* flows.

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APPENDIX

We assume that, in equilibrium, all factors are fully employed for each country i $(i = 1, 2, 3)$, so that:

$$
\begin{aligned}
K_i \geq\ & a_{KXi}\left[n_i \sum_{j=1}^{3} x_{ij} + x_{ii}\left(\sum_{j=1}^{3} h_{3,j} + \sum_{j\neq i} h_{2,ji} + \sum_{j\neq i} h_{2,ij}\right)\right. \\
& \left. + \sum_{j\neq i} v_{ji}\left(\sum_{j=1}^{3} x_{ij}\right)\right] + a_{Koi}o_i + a_{Kni}n_i + a_{Kmi} \\
& \times \left\{\left[3 + \sum_{j\neq i} \gamma_{ij}\right] h_{3\cdot i} + [2 + \gamma_{ij}]h_{2\cdot ij} + [1 + \gamma_{ij}]v_{ij}\right\} \\
S_i \geq\ & a_{SXi}\left[n_i \sum_{j=1}^{3} x_{ij} + x_{ii}\left(\sum_{j=1}^{3} h_{3,j} + \sum_{j\neq i} h_{2,ji} + \sum_{j\neq i} h_{2,ij}\right)\right. \\
& \left. + \sum_{j\neq i} v_{ji}\left(\sum_{j=1}^{3} x_{ij}\right)\right] + a_{SZi}o_i \sum_{j=1}^{3} z_{ij} + a_{Soi}o_i + a_{Sni}n_i \\
& + a_{Smi}\left(h_{3,i} + \sum_{j\neq i}\left(h_{2,ij} + v_{ij}\right)\right) \\
U_i \geq\ & a_{UXi}\left[n_i \sum_{j=1}^{3} x_{ij} + x_{ii}\left(\sum_{j=1}^{3} h_{3,j} + \sum_{j\neq i} h_{2,ji} + \sum_{j\neq i} h_{2,ij}\right)\right. \\
& \left. + \sum_{j\neq i} v_{ji}\left(\sum_{j=1}^{3} x_{ij}\right)\right] + a_{UYi} \sum_{j=1}^{3} t_{Yij} Y_{ij} + a_{UZi}o_i \sum_{j=1}^{3} z_{ij} \qquad (2.A.1)
\end{aligned}
$$

Multilateral current account balance for each country i ($i = 1, 2, 3$) requires the following to hold:

$$\begin{aligned}
& o_i p_{Zi}(z_{ij} + z_{ir}) + (n_i + v_{ji} + v_{ri}) p_{Xi}(x_{ij} + x_{ir}) + p_{Yj} Y_{ij} + p_{Yr} Y_{ir} \\
& \quad + \frac{1}{1-\varepsilon}([h_{2,ij} + h_{3,i}] p_{Xj} x_{jj} + [h_{2,ir} + h_{3,i}] p_{Xr} x_{rr}) \\
& \quad + \frac{1}{1-\varepsilon}(v_{ij} p_{Xj}[x_{jj} + x_{ji} + x_{jr}] + v_{ir} p_{Xr}[x_{rr} + x_{ri} + x_{rj}]) \\
& = o_j p_{Zj} z_{ji} + o_r p_{Zr} z_{ri} + (n_j + v_{ij} + v_{rj}) p_{Xj} x_{ji} \\
& \quad + (n_r + v_{ir} + v_{jr}) p_{Xr} x_{ri} + p_{Yi}(Y_{ji} + Y_{ri}) \\
& \quad + \frac{1}{1-\varepsilon}(h_{2,ji} + h_{3,j} + h_{2,ri} + h_{3,r}) p_{Xi} x_{ii} \\
& \quad + \frac{1}{1-\varepsilon}(v_{ji} + v_{ri}) p_{Xi}(x_{ii} + x_{ij} + x_{ir})
\end{aligned} \tag{2.A.2}$$

The first line in equation (2.A.2) represents the exports of intermediate and final goods of country i. The second and third lines represent income earned on capital invested by country i in horizontal and vertical affiliates, respectively, in country's j and r (denoting the ROW). The fourth line represents country i's imports of goods from j and r. The fifth and sixth lines represent i's repatriation of income on capital of countries' j and r invested in country i in horizontal and vertical affiliates, respectively.