Finding Vertical Multinational Enterprise Activity

Jeffrey H. Bergstrand
Department of Finance
Mendoza College of Business and
Kellogg Institute for International Studies
University of Notre Dame and CESifo
Notre Dame, IN 46556 USA

Peter Egger
Department of Economics
University of Munich, CESifo,
and Ifo Institute
D-80539 Munich
Germany

Abstract

The literature on foreign direct investment has generally failed to find strong systematic evidence of "vertical" motivations in aggregate data. First, we show that the goal of finding vertical motivations for foreign affiliate sales by estimating the standard 2x2x2 "Knowledge-Capital" model was considerably hampered due to the limitation of only 2 factors (skilled and unskilled labor) and 2 countries. The introduction of a third factor (physical capital) and a third country (*ROW*) to the Knowledge-Capital model – that is, a 3-country Knowledge-and-Physical-Capital model – provides sharper testable hypotheses for vertical versus horizontal MNE activity. We introduce differences in relative factor endowments into the Knowledge-and-Physical-Capital model of Bergstrand and Egger (2007) to motivate sharp testable hypotheses for distinguishing between vertical and horizontal multinational enterprise activity in aggregate bilateral data. The key economic insight is that horizontal MNE headquarters will be relatively more abundant than vertical MNE headquarters in countries that are abundant in *physical capital relative to knowledge capital*, because of the multi-plant (single-plant) structure of horizontal (vertical) MNEs – assuming plants (headquarters) use physical (knowledge) capital relatively intensively in their setups. Second, one of the implications of general equilibrium models of MNE activity is the "interconnectedness" of foreign affiliate sales and trade flows. Our Knowledge-and-Physical-Capital model also provides testable hypotheses for the relationships between relative factor endowments and bilateral trade flows. We confirm the robustness of vertical motivations for MNEs by identifying theoretically and empirically the relationships between relative physical-capital, relative skilled-labor, and relative unskilled-labor endowments with bilateral exports of vertical MNEs from foreign-based plants – distinct from national firms' export flows.

September 2009

Keywords: Foreign Direct Investment, Foreign Affiliate Sales, Multinational Firms, International Trade
JEL Classifications: F11, F12, F21, F23

Finding Vertical Multinational Enterprise Activity

1. Introduction

The enormous increase in the past two decades of foreign direct investment (FDI) by multinational enterprises (MNEs) headquartered in relatively knowledge-and-physical-capital rich Western European countries, Japan, and the United States into relatively unskilled-labor-abundant China and India has raised considerable concern over the negative effects of foreign investment – and, in general, "globalization" – on developed economies' real wage rates and standards of living, as recently popularized in Thomas Friedman's (2005) *The World is Flat*. Yet, a comprehensive survey of the empirical FDI literature in Blonigen (2005) concludes that this "vertical motivation" for FDI between nations – FDI arising due to differences in relative factor endowments – is "not prevalent in the general [aggregate, empirical] FDI patterns" (p. 396). Thus, conventional wisdom and cursory observation suggest that relative factor-endowment differences should significantly influence the general pattern of foreign affiliate sales (FAS) and FDI activity (cf., Friedman, 2005). Yet, seemingly carefully executed econometric evidence rejects this hypothesis (cf., Blonigen, 2005). Once again in economics, conventional wisdom and systematic empirical evidence are at odds.

This paper addresses the issue of finding evidence of vertical MNE activity by examining the seemingly "schizophrenic" treatment of *physical capital* in modern empirical analyses of FAS and FDI. On the one hand, the modern general equilibrium theory of MNE activity focuses upon the role of intangible assets of firms – such as knowledge capital – for explaining MNEs' existence, cf., Markusen (2002). Using the "Knowledge-Capital" (KC) model, recent empirical analyses have focused upon the roles of relative economic sizes to explain "horizontal" MNE activity and relative skilled-to-unskilled labor ratios to explain "vertical" MNE activity, cf., Carr, Markusen, and Maskus (2001, 2003), Blonigen, Davies, and Head (2003), Markusen and Maskus (2001, 2002), Braconier, Norbäck, and Urban (2005), and Davies (2008). Motivated by a two-factor model with only skilled and unskilled labor, physical capital plays no role theoretically or empirically in these analyses.

On the other hand, the recent extension of the international economics literature to recognize "heterogenous productivities" among national, exporting, and multinational enterprises reveals that MNEs tend to be very *physical-capital-intensive* (as well as human-capital-intensive) firms and MNEs tend to be headquartered in relatively *physical-capital-abundant* (as well as human-capital-abundant) countries, cf., Bernard, Jensen and Schott (2005) and Helpman (2006). Moreover, even one of the measures of FDI in the U.S. Bureau of Economic Analysis (BEA) data uses the share of a MNE's real investment in *physical* plant and equipment in a foreign affiliate. This dichotomous treatment of physical capital in the MNE literature and the apparent absence of "vertical motivations" for FDI in the bilateral aggregate data suggests re-examining the role of physical capital.

This paper addresses physical capital's role theoretically and empirically and offers two potential contributions. First, we introduce differences in relative physical capital endowments – alongside relative skilled and unskilled labor endowments – into the 3-factor, 3-country, 2-good "Knowledge-and-Physical-Capital" model of Bergstrand and Egger (2007) and provide some testable hypotheses for predicted vertical and horizontal FAS that are different than those suggested by the workhorse 2-factor, 2-country "Knowledge-Capital" model. Bergstrand and Egger (2007) presented a 3-country, 3-factor, 2-good extension of Markusen's 2-country, 2-factor, 2-good "Knowledge-Capital" model, but assumed *identical* relative factor endowments to focus only on the roles of GDP size and similarity for explaining the coexistence of *horizontal* bilateral FAS/FDI flows and intra-industry trade flows for countries with identical absolute and relative factor endowments and for motivating a theoretical rationale for estimating "gravity equations" of bilateral FAS and FDI flows alongside bilateral trade flows; vertical MNEs played no role in Bergstrand and Egger (2007). We find here that general equilibrium relationships between relative skilled-to-unskilled-labor ratios and bilateral FAS are sensitive to relative endowments of physical capital and to the presence of a third country (*ROW*).

Specifically, we evaluate empirically the roles of relative skilled-to-unskilled-labor ratios *and* physical-capital-to-skilled-labor ratios – alongside standard controls for economic size and similarity (horizontal MNEs), investment costs, and trade costs – for explaining bilateral aggregate FAS. We find statistically significant relationships between both relative factor endowment variables and FAS, in a manner consistent with the theory. The key economic insight is that horizontal MNE headquarters will be relatively more abundant than vertical MNE headquarters in countries that are abundant in *physical capital relative to knowledge capital*, because of the multi-plant (single-plant) structure of horizontal (vertical) MNEs – assuming plants (headquarters) use relatively intensively physical (knowledge) capital in their setups. The theoretical model suggests fourth-order polynomial relationships between relative skilled labor shares and relative physical capital shares with FAS; construction of Edgeworth boxes for empirical bilateral FAS provides a transparent way to confirm empirically the fourth-order-polynomial relationships of relative factor endowments with MNE activity found using standard regressions. In this regard, we follow the improvements introduced by Braconier, Norbäck, and Urban (2005) of a broader sample of bilateral FAS flows (beyond just U.S. inward and outward flows), using measures of relative factor endowments corresponding conceptually to the Edgeworth box, and employing empirically predicted FAS flows in an Edgeworth box in order to evaluate visually the "explanatory power" of the empirical regressions, alongside conventional coefficient estimates' significance levels. Interestingly, we find evidence suggesting – consistent with recent firm-level categorizations in Alfaro and Charlton (2007) – that vertical MNE motivations are *just as important* as horizontal MNE motivations!

Second, as Blonigen (2005, p. 398) notes, one of the useful implications of formal general equilibrium models of MNEs is the potential "interconnectedness" of FAS with trade flows. Since our theoretical general equilibrium model can also predict trade flows, for robustness we show how the model can also predict *simultaneously* actual aggregate bilateral trade flows of national firms – as well as of vertical MNEs with plants abroad. We adopt our methodology for explaining relationships between bilateral FAS with relative factor endowments to explaining relationships between bilateral trade flows with relative factor endowments. In the presence of knowledge as well as physical capital, our methodology provides testable hypotheses between relative factor endowments and trade flows and empirical support for these hypotheses. We find evidence for vertical motivations for MNE activity *also in bilateral aggregate trade flows.*

In summary, our model provides substantive empirical evidence for vertical FAS, alongside horizontal FAS, in a manner consistent with explaining bilateral trade flows. Hence, the "vertical motivations" for MNE activity that Blonigen (2005) suggests have evaded empirical researchers *are* prevalent in the bilateral aggregate FAS *and* trade data – while retaining the importance of the "horizontal motivation" – and *physical capital matters* in the explanation.

2. Limitations of the 2x2x2 Knowledge-Capital for Finding Vertical MNEs

This section has three parts. In the first part, we review briefly some seminal contributions to this literature. In the second part, we identify explicitly why the limitation of the 2x2x2 Knowledge-Capital model to only 2 factors and 2 countries virtually doomed "estimation" of it to failure. In the third part, we address specifically the goals of this paper and its potentially "testable" hypotheses.

2.1. Related Literature

Markusen (2002, Ch.1), Barba Navaretti and Venables (2004, Ch. 6), and Blonigen (2005) provide useful summaries of empirical determinants of FDI/FAS. First, these articles make the important distinction between the "firm-and-industry" economic determinants of FDI/FAS in the recent MNE literature on heterogeneous-firm productivities versus the "country" economic determinants of FDI/FAS studies.[1] The analysis of firm-industry determinants emphasizes two issues: (i) firm- versus plant-level economies of scale in production and (ii) firm heterogeneity in productivity. Some empirical analyses of industry-specific FAS flows, such as Brainard (1997), have explained cross-industry variation in the level (or share) of FAS using estimates of firm-level scale economies and of plant-level scale economies with some success. However, these studies typically have been confined to U.S. data only, since few countries have credible measures of firm- and plant-level scale economies; empirical support for these variables has been modest. Using recent firm- and plant-level data by industry in select countries, a second and rapidly

[1]These literatures complement each other. Note that there are "two concepts of FDI." The first is FDI as measured using balance-of-payments statistics; there are three measures using this data, one of which uses shares of foreign affiliates' real investment expenditures on physical plant and equipment provided by parent corporations. This measure of foreign direct investment is referred to henceforth as "FDI." The second "concept" of FDI measures MNEs' activities using data on foreign affiliates' employment, production, and sales; this concept of FDI is referred to as "FAS." It is very important to note that the literature still typically uses these two terms interchangeably, although a few studies have correctly noted explicitly the distinction, cf., Markusen (2002, p. 8). We will distinguish FDI from FAS, cf., Borga and Yorgenson (2002) for a useful discussion within the context of U.S. data.

growing literature has been examining the role of (exogenous) heterogeneity in productivity levels for explaining *across firms* within an industry the self-selection of firms into non-exporting, non-MNE firms serving the home market only, exporting firms, and MNEs, cf., Bernard, Jensen and Schott (2005) and Helpman (2006). One of the notable empirical insights uncovered by this line of research is that MNEs tend to be *physical-capital* intensive in production (as well as knowledge-capital intensive) and MNEs tend to exist in *physical-capital* abundant (as well as knowledge-capital abundant) countries, which clearly supports our motivation for examining systematically theoretically and empirically the role of physical-capital endowments.[2] However, this literature's firm-industry emphasis is quite distinct from our focus, which will be on the role of country economic characteristics for explaining the determination of large *bilateral aggregate* FAS flows.[3]

By contrast, the "country" characteristics approach tries to explain the variation in bilateral aggregate FAS or FDI flows *across country pairs* (and often over time also) using country-specific economic variables and has focused upon four sets of such variables: (i) economic size (or GDPs); (ii) relative factor endowments; (iii) costs or barriers to trade and FDI/FAS; and (iv) relative tax rates. Markusen (1984) provides the first formal general equilibrium (GE) "horizontal" motivation for MNEs (HMNEs) where, in the presence of given barriers to trade and FDI and firm-and-plant-level scale economies, HMNEs will arise and displace exporting firms as market size grows. Helpman (1984) provided the first formal GE "vertical" motivation for MNEs (VMNEs), where VMNEs will arise in the presence of relative factor-endowment differences. Markusen et al. (1996) and Markusen (2002) integrated these two motivations in the "Knowledge-Capital" model.

Our study focuses upon *cross-country-pair* variation in bilateral aggregate FAS flows, and thus extends the cross-country KC literature. As Blonigen (2005) notes, the first attempts to evaluate

---

[2]The empirical results using firm- and plant-level data tend to support the theory, which includes that – due to fixed costs of production and of entering markets – the (exogenously) largest and most productive firms tend to select into MNEs, the slightly smaller and less productive firms tend to select into exporting, and the smallest and least productive firms tend to select into serving just the domestic market.

[3]In the spirit of discussion in Helpman (2006, p. 592), we note that within industry heterogeneity in firms' productivities is unnecessary to explain "large volumes" of trade, FAS, and FDI across country pairs; instead, it is essential to explain firm-industry panel data. Country characteristics, such as relative factor proportions, can potentially explain large bilateral aggregate trade, FAS, and FDI flows.

empirically the implications for MNE foreign affiliate sales of cross-country (and over time) economic characteristics based upon formal GE models are Brainard (1997) and Carr, Markusen, and Maskus (2001).[4] Guided by a two-factor, two-country, two-sector model, Brainard (1997) finds that FAS between country pairs is explained largely by horizontal motives; she finds that factor-proportion differences (measured by differences in per capita incomes) essentially reduce FAS "contrary to conventional wisdom" (p. 520). Carr, Markusen, and Maskus (2001, henceforth, CMM) was the first paper to evaluate the 2x2x2 Knowledge-Capital GE model. Relevant country economic characteristics determining foreign affiliate sales of parent country *i*'s MNEs in host country *j* included the two countries' economic sizes and similarities (influencing HMNE activity), differences in relative skilled-to-unskilled-labor endowments (influencing VMNE activity), bilateral trade and investment costs (influencing both activities), and nonlinear interactions of a few of these variables. CMM (2001) argued that the empirical findings supported "acceptance" of the KC model relative to either a HMNE or a VMNE model.

However, as with any path-breaking work, room for clarification and enhancement exists. For instance, Markusen and Maskus (2002) qualified some of their own empirical findings in CMM (2001), noting that one could not reject empirical support for the simpler HMNE model relative to the KC model once more nonlinearities were included. Blonigen, Davies, and Head (2003, henceforth, BDH) argued from an alternative perspective that the HMNE model could not be rejected relative to the KC model. The BDH specifications included instead absolute differences in relative factor endowments and showed empirically that the (negative) effect of relative skilled-to-unskilled-labor ratios on foreign affiliate sales of MNEs was the opposite of that found in CMM, a finding similar to Brainard (1997), and the BDH results were interpreted as rejecting the KC model in favor of horizontal MNEs only. Consequently, conventional wisdom about the importance of relative factor endowments on bilateral aggregate FAS finds weak support, as emphasized in our introductory quote from Blonigen (2005). But, as CMM (2001,2003), BDH (2003), and Blonigen (2005) all note, "tests" of the importance of relative factor proportions for influencing FAS are made very difficult because of the complex, nonlinear, nonmonotonic

[4]Econometric analyses of FAS and FDI flows have been published for over 25 years. However, early analyses were not predicated on formal GE theoretical models.

models of MNE behavior, which lack closed-form solutions allowing easy econometric specification. Finally, Braconier, Norbäck, and Urban (2005, henceforth, BNU) made three significant contributions to this issue (which we adopt also and address shortly), finding more success in identifying foreign affiliate sales of vertical MNEs.

2.2. Limitations of the 2x2x2 KC Model for Finding VMNEs

We argue here that the evidence against the KC model in favor of just HMNEs explaining bilateral aggregate FAS flows should actually come as no surprise if one examines closely the theoretical predictions of the KC model – limited to a 2-factor, 2-country world; in the following, reference to the "KC model" necessarily implies a 2-factor, 2-country world. Figures 1a-1b from Markusen (2002) and Figure 1c from BNU (2005) help to illustrate this point, based upon the KC model. Figure 1a presents the Edgeworth box (Figure 7.1 from Markusen, 2002, p. 143) relating country *i*'s (*j*'s) share of the two countries' skilled labor stocks along the vertical axis, country *i*'s (*j*'s) share of the two countries unskilled labor stocks (also called by Markusen the "composite factor") along the horizontal axis, and the equilibrium "regimes" of types of firms (see Figure 1a's index). Depending upon relative skilled-to-unskilled-labor ratios, HMNEs ("Multinational firms only"), VMNEs ("Vertical firms"), NEs ("National firms only"), or "Mixed regimes of national and multinational firms" may be found in equilibrium. Cursory examination of this figure suggests two main propositions evaluated in the KC literature. First, when two countries are identical in economic size and relative factor endowments, both countries will have only HMNEs in equilibrium; there will be *no* VMNEs (nor NEs, for that matter) in equilibrium. Second, however, when country *i* is moderately relatively skill abundant (moving left from the center cell, or towards the left vertical axis), HMNEs based in *i* will still exist in equilibrium (because HMNEs' headquarters setups use relatively more skilled labor than NEs' headquarters setups). Yet when country *i* becomes even more relatively skill abundant (further left), Figure 1a suggests that HMNEs cease to exist in *i*, but actually HMNEs are joined by VMNEs (because it becomes profitable for *i* to "outsource" final goods production to *j* and ship output anywhere in the world).

Initial empirical "estimation" of the KC model to find both HMNEs and VMNEs in *i* was virtually doomed to fail for the following reason. Figure 1b (actually Table 7.2 from Markusen, 2002) reports the sum of different types of operations in existence in equilibrium, which is the data underlying Figure 1a. Consider three results. First, at the center cell (when the two countries are identical in absolute and relative factor endowments), both countries have HMNEs headquartered in their own countries, with plants in their home and foreign markets; no VMNEs or NEs are profitable (0.011=0.010+0.001), consistent with Figure 1a. Second, moving leftward, country *i* eventually becomes relatively smaller and more skilled-labor abundant, making HMNEs based in *i* the only profitable firms (0.010), consistent with Figure 1a. Third, continuing leftward, the three columns on the far left indicate that relatively skilled-labor-abundant *i* will headquarter both HMNEs and VMNEs (2.010 = 2.0 + 0.010), as explained in Markusen (2002, p. 145). That is, for the identical ratio of skilled-to-unskilled labor in *i* – say, the far left column and middle row – FAS for home country *i* in host country *j* is motivated by both horizontal and vertical activity! In fact, careful examination of the entire first (LHS) column of Figure 1b reveals that HMNEs exist in equilibrium for moderate levels of skill abundance, but VMNEs exist also for high, moderate, and low levels of skill abundance. The fundamental problem with using the 2x2x2 KC model to distinguish VMNE from HMNE activity is this: overlap of vertical and horizontal MNEs (cells in Figure 1b with values of either 2.01, 12.01, or 102.01) comprise *18 percent* of the 190 cells in the upper-left quadrant of Figure 1b, making it very difficult to distinguish VMNE vs. HMNE activity using only relative factor endowments of skilled-to-unskilled labor.

Thus, the CMM (2001) econometric "estimation" of the KC model to find both HMNEs and VMNEs was compromised from the start because the Edgeworth surface described bilateral FAS motivated by both HMNEs and VMNEs at the same skilled-to-unskilled-labor ratio – even if the central regression "specification" was mapped directly from the theory as in BNU (2005), i.e., factor shares of the Edgeworth box.[5] BNU (2005) made a useful contribution to this literature by generating a regression specification that mapped "directly" from the theoretical framework, taking into account properly the geometric considerations of Edgeworth boxes. Motivated by this important analytical consideration

[5]In fairness, CMM (2003) candidly indicated that finding a "central regression specification" is a very difficult task.

alongside employing a broader data set (in terms of country pair coverage) of FAS bilateral flows, BNU (2005) argued that – when properly specified – VMNEs could be found in the data, alongside HMNEs. Figure 1c (from BNU, 2005) illustrates their "empirically predicted" FAS_{ij}. However, while their empirically predicted FAS surface is visually similar to the theoretically predicted FAS surface in Markusen (2002, figure 10.1, p. 221), the problem still remains. Where BNU predict the "peak of vertical FDI_{ij}" in Figure 1c – when *i* is economically smaller and skilled–labor abundant relative to *j* – the data cells in Figure 1b inform us that both vertical and horizontal MNEs can be headquartered in *i* (note the cell entry 2.010 in the far left column in rows 8, 9, 10, and 11 from the bottom). Thus, BNU (2005) does not resolve the issue empirically because the problem lies in finding – in Edgeworth-box space – relative factor endowment configurations where VMNE headquarters can be *clearly distinguished* from HMNE headquarters.

2.3. Goals of This Paper

In this paper, we find evidence of vertical MNE activity – both in FAS and trade data. Moreover, we show that vertical and horizontal MNE activity is sensitive to relative *physical* capital endowments, an issued ignored in those studies.[6] Our approach is premised upon the following three simple – and plausible – assumptions: (1) production requires unskilled labor, alongside knowledge and physical capital, (2) headquarters setups require knowledge capital (or skilled laborers), and (3) plant setups require physical capital – all assumptions embedded in Bergstrand and Egger (2007).[7] As in the KC literature, we also distinguish between three types of firms: national exporting firms (NEs), VMNEs, and

---

[6]The other major difference of our model from the previous KC literature is the introduction of a third country, *ROW*. As is well established theoretically and empirically from an extensive gravity equation literature, bilateral flows (trade or FAS) between a pair of countries are sensitive to the level of economic activity, prices, etc. in the *ROW*, cf. Anderson and van Wincoop (2003) and Bergstrand and Egger (2007). We address the relevance of our third country theoretically and empirically in more detail later.

[7]As discussed in Bergstrand and Egger (2007, footnote 13), all that is required is that "setups of plants (firms) are *relatively* more physical (knowledge) capital intensive, which we conjecture is true empirically" (p. 287).

HMNEs.[8]

The *key question* we ask is: In a world with three factors of production (unskilled labor, skilled labor, and physical capital), what are the relative factor endowments of countries that give rise to locating headquarters and plants of NEs, VMNEs, and HMNEs, theoretically and empirically? First, NEs have one headquarters and one plant in the same country to benefit from economies of scale in production. If unskilled labor is relatively abundant in country *i*, then *i* will tend to headquarter exporting firms (relative to VMNEs or HMNEs) to benefit from economies of scale in production (for given trade and investment costs). Second, VMNEs are created when a firm can benefit from establishing a headquarters in a skilled labor (or knowledge-capital) abundant country *i* and a plant in an unskilled labor abundant country *j*, because headquarters setups require skilled labor and production requires unskilled labor. However, a plant setup requires physical capital (obtained by "greenfield" or "brownfield" FDI). So VMNE headquarters will be abundant in country *i* if it is scarce in unskilled labor but abundant in skilled labor relative to physical capital to setup one headquarters at home (and one plant in a "low-cost" foreign country abroad). Third, the motivation for HMNEs is – for country pairs with similar relative factor endowments – the avoidance of high transport costs (relative to investment costs). Hence, HMNEs differ from VMNEs by having a single headquarters (like VMNEs) but multiple plants around the world serving similar countries with local production. If headquarters setups require skilled labor (or knowledge-capital) but plant setups require physical capital, country *i* will have a comparative advantage in headquartering HMNEs relative to VMNEs if physical capital is abundant relative to skilled labor in *i* (and unskilled labor, needed for production, is relatively scarce also).

Consequently, the *key contribution* of this paper is the prediction that HMNEs (VMNEs) will be headquartered in countries abundant (scarce) in *physical capital relative to knowledge capital* (for given unskilled labor endowments), under the assumption that multi-plant HMNEs use intensively in setups

[8] Recently, research also suggests the existence of "hybrid" (or "complex") MNEs, integrating vertical and horizontal motivations. While such MNEs exist, incorporating them here would push the model beyond a manageable scope, and should be pursued in the future. We note that a recent study, Alfaro and Charlton (2007), has compiled a large firm-level data set (using WorldBase Data) that categorizes 216,996 parent-subsidiary combinations into 112,939 vertical and 104,057 horizontal relationships. They found only "50,000 complex subsidiaries [of these 216,996 relationships]" (p. 11). Thus, it still remains useful to address understanding the vertical and horizontal motivations distinctly for cross-country-pair variation in bilateral aggregate FAS.

physical capital relative to knowledge capital (relative to single-plant VMNEs) and physical capital is imperfectly mobile (allowing FDI). This notion gives rise to some different and additional theoretical predictions and empirical relationships between relative factor endowments and FAS than in the 2x2x2 KC model – which turns out to be a special case of our model (with only skilled and unskilled labor). This simple extension of the KC model to three factors and three countries – that is, a KAPC model with differing relative factor endowments – suggests at least five *new* propositions (1b-3b below) in addition to maintaining the well-established first proposition (1a below) from the KC model:

(1a) VMNE headquarters will be abundant in countries that are very abundant in skilled labor relative to unskilled labor (as in the KC model).

Using the 3-country Knowledge-and-Physical-Capital model, five new propositions surface in our study:

(1b) HMNE headquarters will be abundant in countries that are only modestly abundant in skilled labor relative to unskilled labor (as in the KC model) but *very small* (unlike the KC model), due to the third country (*ROW*).

(2a) HMNE headquarters will be abundant in countries that are very abundant in *physical capital relative to knowledge capital* (and unskilled labor), due to the multi-plant structure of HMNEs and plant setups being physical-capital intensive.

(2b) VMNE headquarters will be abundant in countries that are very abundant in *knowledge capital relative to physical capital* (and unskilled labor), due to the single-plant structure of VMNEs and plant setups being physical-capital intensive,

and, due to the "interconnectedness" of FAS and trade because of the general equilibrium structure,

(3a) Exports from country *i* to country *j* will be abundant when country *i* is abundant in unskilled labor (relative to knowledge and physical capital), but abundant in *physical capital relative to knowledge capital*, due to VMNEs with plants in *i* but headquarters elsewhere.

(3b) Exports from country *i* to country *j* will be abundant when country *i* is abundant in unskilled labor (relative to knowledge and physical capital), but abundant in *knowledge capital relative to physical capital*, due to NEs with headquarters and single plant based in *i*.

We confirm each proposition empirically in this paper and find evidence of VMNEs – using FAS *and* trade data.

The remainder of this paper is as follows. In section 3, we summarize our 3-factor, 3-country, 2-good Knowledge-and-Physical-Capital (KAPC) model with asymmetric relative factor endowments. In section 4, we use the numerical version of our KAPC model to postulate several theoretical hypotheses about relative factor endowments, FAS, and trade. In section 5, we examine empirically the determinants of bilateral aggregate FAS and trade flows. Section 6 concludes.

3. The Theoretical Framework: A Summary of the Knowledge-and-Physical-Capital (KAPC) Model

The model we use is a more general version of the 3-country, 3-factor, 2-good model in Bergstrand and Egger (2007) by allowing differences in relative skilled-to-unskilled-labor ratios *and* physical-capital-to-unskilled-labor ratios, consequently generating both horizontal and vertical MNEs in equilibrium. Bergstrand and Egger (2007) is an extension of the 2x2x2 Knowledge-Capital (KC) model in Markusen (2002) with national exporters (NEs), horizontal MNEs (HMNEs), and vertical MNEs (VMNEs), but assumed identical relative factor endowments to focus on the roles of economic size and similarity; consequently, no VMNEs surfaced in Bergstrand and Egger (2007), except in one sensitivity analysis.[9] The demand side in the KAPC model is analogous to that in the KC model. However, the KAPC model extends the KC model in two ways. The first distinction is to use three primary factors in the production of the differentiated good. We assume unskilled and skilled labor are immobile internationally, but physical capital is imperfectly mobile in the sense that MNEs will endogenously choose the optimal allocation of domestic physical capital between home and foreign locations to maximize profits; analytically, this is in the tradition of "real" international economic models of FDI, cf., Mundell (1957), Jones (1967), and Helpman and Razin (1983). However, we impose large costs to transferring physical capital internationally; hence, returns to physical capital need not be equalized, cf., Bergstrand and Egger (2007). This is also consistent with the BEA definition of foreign "direct

[9]The present model allows for 2-county and 3-country HMNEs also.

investment positions" using domestic and foreign-affiliate shares of real fixed investment by MNEs' parents.[10]

The second distinction of our KAPC model from the KC model is to introduce a "third country." The presence of the third country helps explain the observed complementarity of bilateral FAS and trade with respect to a country pair's economic size and similarity and that bilateral FDI and FAS tend empirically to be as well explained by a gravity equation as bilateral trade flows are. One implication of a third country is that (in equilibrium) both two-country HMNEs and three-country HMNEs may surface. As BDH (2003) and Blonigen (2005) note, it is unclear what the implications of the typical "2-country" assumption are when guiding empirical work using bilateral flows in an N-country world. We explore later in more detail the relevance of the *ROW*.[11]

As noted, vertical MNEs played no role in explaining FAS and trade patterns in Bergstrand and Egger (2007), except in one sensitivity analysis. By contrast, vertical MNEs play a central role here. Distinct from Brainard (1997), CMM (2001,2003), BDH (2003), BNU (2005), and Bergstrand and Egger (2007), we distinguish in this paper theoretically and empirically between differences between two countries' physical-capital-to-skilled-labor ratios and differences between the countries' skilled-to-unskilled-labor ratios for explaining the pattern of FAS. Even though human and physical capital tend to be complements in production, differences in the relative factor intensity requirements of setting up headquarters *relative to* setting up plants help to suggest different theoretical effects of the two relative factor-endowment differences on FAS. Moreover, in contrast to most preceding theoretical analyses using the notions of FDI and FAS interchangeably (except Bergstrand and Egger, 2007), we explicitly distinguish FDI from FAS and actually have FDI (imperfectly-mobile physical capital) in the theoretical

---

[10] 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. The numeraire homogeneous good will be produced using only unskilled labor.

[11] Since the KC and KAPC models both use two final goods (one differentiated and one homogenous), we need not refer any more to a "2-good" model.

model, while retaining the usual perfectly-immobile skilled labor, S, and unskilled labor, U.[12] Since the structure and calibration of the model is described explicitly in Bergstrand and Egger (2007), for brevity we present the model in Appendix A and a description of the calibration of the model in Appendix B of this paper.

4. Theoretical Results

The numerical version of our GE model can be used to generate "testable propositions" about pairs of countries' relative factor endowments, HMNE activity, and VMNE activity. We focus on predicting theoretically the numbers of HMNEs based in home country *i* with plants in *i, j*, and/or *ROW* and VMNEs based in home country *i* with plants in *j* or *ROW*, contingent upon different configurations of relative factor endowments. Due to the presence of three factors, three countries, and highly nonlinear relationships, there are potentially an enormous number of relationships to explain. To make the theoretical results tractable under journal space constraints, we organize material according to "testable" hypotheses, as is standard in the literature.

In section 4.1, we show that the main proposition about the relationship between VMNE activity and relative skilled-to-unskilled-labor ratios established in the 2x2x2 KC literature surfaces in our model as well (since the KC model is a special case of the KAPC model). However, we show how the 3-factor,

---

[12]Bergstrand and Egger (2007) showed that, due to the presence of physical and human capital, the behavior of FAS differed from FDI flows (as functions of economic size and similarity). Due to space constraints, we focus our analysis here on FAS behavior only; the reason is that the empirical Knowledge-Capital literature has focused on FAS. In the typical 2x2x2 model, headquarters use home skilled labor exclusively for setups; home (foreign) plants use home (foreign) skilled labor for setups (cf., Markusen, 2002, p. 80). With only immobile skilled and unskilled labor, the 2-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," in the tradition of "real" theories of international investment. That is, for analytical simplicity, we follow the tradition set in such seminal papers as Mundell (1957, pp. 321-323), Jones (1967), and Helpman and Razin (1983) and allow physical capital to "move" to where firms can maximize profits. In Jones' words, "Foreign [direct] investment involves a change in location, but not in ownership, of real capital equipment" (p. 3). Practically speaking, it is easiest to think of FDI as "greenfield" investment. The model is real, consistent with Markusen (2002) and the modern MNE literature; there are no paper assets. Moreover, while physical capital can be utilized in different countries, ownership of any country's endowment of such capital is immobile. In reality, 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, cf., Borga and Yorgason (2002, p. 27). Note also that Markusen (2002, p. 8) does conscientiously clarify that the "models in this book are addressed more closely to affiliate output and sales than to investments stocks."

3-country KAPC model uses the assumption of relative physical-to-knowledge-capital factor intensities in plant-versus-headquarters *setups* and the *third-country assumption* to suggest a different relationship between HMNE activity and relative skilled-to-unskilled-labor ratios compared to the 2-factor, 2-country KC model, allowing better potential for finding VMNEs distinct from HMNEs. In section 4.2, we examine two new propositions about HMNE and VMNE activity and relative physical capital endowments precluded by the 2-factor KC model (with only skilled and unskilled labor). In section 4.3, for robustness, we exploit the "interconnectedness" of FAS and trade flows – due to the general-equilibrium relationships – to suggest two new propositions about the relationships between VMNEs, NEs, relative physical-to-knowledge-capital endowments, and exports from *i* to *j*.

4.1. Skilled Labor, Unskilled Labor, and Horizontal and Vertical MNEs

In a 3-factor, 3-country world, however, Edgeworth boxes actually are *slices* from an Edgeworth "cube" (for any given level of *ROW* endowments). To focus as in the earlier literature on the relationships between skilled labor, unskilled labor, and horizontal and vertical MNEs, we consider initially the Edgeworth box relationship between country *i*'s share of countries *i* and *j* skilled labor stocks (denoted s_i) for a given skilled labor stock in *ROW*, country *i*'s share of *i*'s and *j*'s unskilled labor stocks (denoted u_i) for a given unskilled labor stock in *ROW*, and the numbers of HMNEs and VMNEs headquartered in *i* – at various percentiles of k_i, which is *i*'s share of *i*'s and *j*'s physical capital endowments, for a given physical capital endowment in *ROW*. Henceforth, FAS_{ij} ($\mathrm{FAS}_{\mathrm{ij}}$) will denote the theoretically (empirically) predicted bilateral FAS of home country *i* in host country *j*. Similar to CMM (2001, 2003), Markusen (2002), BDH (2003), BNU (2005), and Davies (2008), we are examining first the relationships among s_i, u_i, and determinants of FAS_{ij}; however, our relationships are conditional upon the level of k_i (a third factor ignored in those studies) as well as the economic size of *ROW* (a third country ignored in those studies). Because we will pursue a regression analysis later, it will be useful to show slices of the Edgeworth cube at the empirical *mean* of the implicit third factor, say k_i. The reason is that – in a regression of bilateral FAS on numerous variables – the interpretation of, say, the coefficient estimate for s_i would be holding, say, u_i and k_i constant at their "means"; thus, the theoretical predictions relating, say, the numbers of HMNEs in i with s_i and u_i are being made at the (empirical) mean of k_i. However, it will be convenient now to note that the empirical means for s_i, k_i, and u_i all range between 0.53 and 0.56. Hence, for convenience, the mean of each factor share is effectively 0.5.

We follow Braconier, Norback, and Urban (2005) in using the shares of factors (here, s_i, u_i, k_i) to help identify the relationships in the Edgeworth box. Thus, like BNU, by using the Edgeworth box we can map the theoretical relationships between relative factor endowments and FAS_{ij} *directly* to the empirical specifications, cf., BNU (2005).

We note now that the discussion above has important implications for hypotheses about the relationship between GDP similarity and FAS_{ij}. In our 3-factor, 3-country world, when k_i is at its mean the cell in the middle of the Edgeworth box relating s_i and u_i may not be where i and j are identically sized in absolute factor endowments (for some given endowments for *ROW*), because k_i may not be precisely 0.5 (but as noted above, it will be close). Moreover, a proportionate reduction in s_i and u_i – such that s_i/u_i is unchanged – but holding k_i at its mean – changes i's and j's relative economic sizes *and also* their relative factor endowments. This differs from the 2-factor KC world examined in all the previous studies (with also 2 countries) where a movement along the Southwest-Northeast (SW-NE) diagonal implies a change in relative economic sizes (absolute factor endowments) of the two countries *without* a change in relative factor endowments; in our 3-factor world, a movement along this diagonal also changes relative factor endowments.

We note now also that it will be very important to remember that Bergstrand and Egger (2007) showed that – holding constant relative factor endowments – horizontal MNE activity in the KAPC theoretical model and in the empirical data could be explained well in terms of (the logarithms of) GDP sizes and similarities. In fact, Bergstrand and Egger (2007) provided a formal theoretical rationale for estimating "gravity equations" of bilateral FAS, confirming the prominence of HMNEs' bilateral FAS in the data. We will address this issue later in more detail in the empirical specifications.

Our first set of hypotheses is that:

(1a) The number of VMNEs based in i with plants in j will be maximized when skilled labor is very abundant relative to unskilled labor in i (relative to j), similar to the KC model.

(1b) The number of HMNEs based in *i* (with plants in *i, j,* and *ROW*) will be maximized when skilled labor is modestly abundant relative to unskilled labor in *i* (relative to *j*), but *i* is *economically small* relative to *j*. However, in our model, this is due to HMNEs based in *i* and the "third-country assumption."

(1c) While Hypothesis 1a was suggested by the 2-factor, 2-country KC model, a novel "testable" consequence of our 3-factor, 3-factor world and Hypotheses 1a and 1b is that FAS of home country *i* in host country *j* (FAS_{ij}) should be a fourth-order polynomial function of country *i*'s share of *i*'s and *j*'s skilled labor (s_i).

Why should FAS_{ij} be a *fourth-order* polynomial of s_i? The rationale is illustrated using Figures 2a and 2b. Figure 2a shows the theoretical relationship between s_i, u_i, and the numbers of HMNEs based in country *i* with plants in *j* (and *ROW*). Figure 2b illustrates the theoretical relationship between s_i, u_i, and the numbers of VMNEs based in *i* with plants in *j*.

Consider first Figure 2b. As in the 2-factor, 2-country KC model, VMNEs in country *i* are a positive function of s_i and a negative function of u_i (at the mean of k_i). Figure 2b confirms – consistent with the 2-factor, 2-country KC model (and Markusen, 2002, figure 7.4, p. 148) – that vertical FAS_{ij} should maximized when home country *i*'s share of *i*'s and *j*'s skilled (unskilled) labor is very large (small) relative to *j*'s. Consistent with the KC model, if country *i* is relatively abundant in skilled labor but relatively scarce in unskilled labor, country *i* can profitably setup VMNE headquarters in *i* and setup plants abroad (such as in *j*), outsourcing production of good *X*, cf., Carr, Markusen, and Maskus (2001), Markusen (2002), and Braconier, Norback, and Urban (2005).

However, as Figure 2a illustrates, at very low levels of s_i country *i* can profitably setup HMNEs in *i* with plants abroad. In our 3-factor, 3-country model, at low levels of s_i – but for a given k_i and u_i at their means (about 0.5) – *i* is relatively abundant in (imperfectly-mobile) physical capital, making it profitable for *i* to setup HMNE headquarters and multiple plants at home and abroad. Also, in a 3-country world, economically small *i* can profitably produce foreign affiliate sales at economically large *j* and *ROW*. This differs from the proposition suggested in BNU (2005) that HMNEs should be maximized at the center of the Edgeworth box, due both to 3 factors *and* 3 countries in our model.[13]

Because VMNEs should be prominent when s_i is high relative to u_i and HMNEs should be prominent when s_i is low relative to u_i, this suggests theoretically that FAS_{ij} may empirically in a regression be a fourth-order polynomial function of s_i holding constant k_i and u_i at their (empirical) means, which are both very close to 0.5 (actually, 0.56 and 0.54, respectively). Importantly, note the *three inflection points* as s_i increases from 0 to 1 at $u_i = 0.5$ and $k_i = 0.5$ (their approximate means), implying a fourth-order polynomial relationship between FAS_{ij} and s_i. This is Testable Hypothesis 1c.

We note two minor issues. First, note that Figures 2a and 2b suggest FAS_{ij} should be negatively – and monotonically – related to u_i. This is testable. Second, we also emphasize the relevance of the third country – *ROW*. Similar to the 2-country KC model, vertical MNEs are maximized when s_i is high relative to u_i. However, slightly different of our Figure 2b from corresponding figure 7.4 in Markusen (2002), figure 2 in CMM (2003), and figure 1 in BNU (2005) is that vertical FAS_{ij} in our Figure 2b is still at a maximum even if s_i is 1 because – with a third country in our model – s_i remains only ½ of the entire world's endowment of skilled labor. This is attributable to our 3-country world.[14]

[13]Note that all figures are indexed between 0 and 100. Hence, the theoretical figures are not designed to predict effects quantitatively, just qualitatively.

[14]In the 2-factor, 2-country KC model, HMNE activity is expected to be maximized in the center of the Edgeworth box, when $s_i = s_j$ ($u_i = u_j$) and $s_i/u_i = s_j/u_j$. Indeed, as Figure 2a shows for our model, when $s_i = s_j$ ($u_i = u_j$) and $s_i/u_i = s_j/u_j$ at $k_i = 0.5$, horizontal FAS_{ij} exists, consistent with the 2-country, 2-factor KC model and with Bergstrand and Egger (2007). However, in our 3-factor, 3-country model, the relationships between s_i, u_i, and horizontal FAS_{ij} differ from the 2x2 KC model. Unlike the KC model, as s_i and u_i decline (moving towards *i*'s origin) – for a given s_i/u_i ratio – HMNEs become *more* prominent because – with the third factor (physical capital) present and unchanged (k_i constant) – physical capital in *i* becomes more abundant relative to skilled labor, making the setup of HMNEs in *i* more profitable. Moreover, if s_i increases relative to u_i as well as s_i and u_i both shrink, setups of HMNEs become even *more profitable*. As Figure 2a illustrates, HMNE activity is actually maximized *not* in the center of the Edgeworth box, but when s_i and u_i are small and *i* is skilled labor rich relative to unskilled labor. This interpretation is confirmed when we increase k_i's share to 0.7. HMNE activity in *i* is maximized when *i* has slightly larger shares of skilled and unskilled labor but *i* is still skilled labor rich relative to unskilled labor (figure not shown for brevity). The difference in our model follows from the relative factor intensity of plants. In our model, headquarters (plants) are setup using skilled labor (physical capital). If *i* is small, it is more likely to have a comparative advantage in having MNEs rather than national exporting firms. However, since multi-plant HMNEs use physical capital in setups, HMNEs can only occur in *i* if *i* is very small in skilled and unskilled labor. VMNEs have only one plant; consequently, the endowment of physical capital in *i* is not as important. The simulation results are also sensitive to the size of *ROW*, which is twice the size of *i* and *j* combined. In reality, most country pairs are much smaller than that, but this would just move the maximum in Figure 2a even closer to the origin at the left.

4.2. Physical Capital, Skilled Labor, and Horizontal and Vertical MNEs

Our second set of hypotheses – entirely precluded in the 2-factor, 2-country KC model – are:

(2a) The number of HMNEs based in i with plants in j will be maximized when i is abundant in *physical capital* relative to knowledge capital (and unskilled labor) relative to j, due to the multi-plant structure of HMNEs and plant setups being physical-capital intensive.

(2b) The number of VMNEs based in i with a plant in j will be maximized when i is abundant in *knowledge capital* relative to physical capital (and unskilled labor) relative to j, due to the single-plant structure of VMNEs alongside the assumed physical capital intensity of plant setups relative to headquarters setups.

(2c) Consequently, our theoretical model and Hypotheses 2a and 2b suggest the testable hypothesis that FAS of home country i in host country j (FAS_{ij}) should be a *fourth-order* polynomial function of country i's share of i's and j's physical capital (k_i) at the means of s_i and u_i.

Figures 2c and 2d illustrate the relationships between k_i, s_i, and the numbers of HMNEs based in i with plants in j (and ROW) and VMNEs based in i with plants in j, respectively, evaluated at the empirical mean of u_i (effectively, 0.5). Consider Figure 2c first. HMNEs have multi-plant structures, whose plant setups are physical-capital intensive. Consequently, HMNEs will be abundant in i if it is abundant in *physical* capital relative to skilled labor (and also unskilled labor), as shown in Figure 2c. By contrast, VMNEs require only one plant (located abroad) along with its headquarters. Since headquarters setups use skilled labor and plant setups use physical capital, VMNEs will be prominent in i when knowledge capital is only slightly more abundant in i than physical capital (as all MNE headquarters setups require more skilled labor than NE setups). Figure 2d illustrates the theoretical relationships between k_i, s_i, and the number of VMNEs headquartered in i with a plant in j at the mean of u_i. Figure 2d suggests that VMNEs will be prominent in i when knowledge capital is slightly more abundant in i than physical capital, due to the single-plant, single-headquarters structure of VMNEs.

The *key* economic insight from our model is that – assuming plants (headquarters) are physical (knowledge) capital intensive in setups – countries that are physical capital abundant (scarce) *relative to* skilled labor should tend to headquarter HMNEs (VMNEs), for given u_i and given endowments in ROW .

Figure 2c suggests that HMNEs will be prominent in *i* when physical capital is abundant relative to knowledge capital in *i*, due to the multi-plant, single-headquarters structure of HMNEs, since plants use physical capital intensively in setups relative to knowledge capital. However, Figure 2d suggests that VMNEs will be prominent in *i* when knowledge capital is slightly more abundant in *i* than physical capital, due to the single-plant, single-headquarters structure of VMNEs. Figures 2c and 2d together suggest that empirical FAS_{ij} may in a regression be a fourth-order polynomial function of k_i – at the empirical means of s_i and u_i (0.54 for both). This is Testable Hypothesis 2c.[15]

We note that our testable hypotheses for each Edgeworth box are characterized at the empirical mean of the (implicit) third factor, u_i in the last set of figures. However, it would be useful to know that the theoretical surfaces shown at the mean of u_i are largely robust to varying the value of u_i. For robustness, we generated the theoretical *k-s* surfaces for the numbers of VMNEs and HMNEs in *i* (akin to Figures 2c and 2d) for values of u_i at the 30^{th} and 70^{th} percentiles as well. In brief, the shapes of the theoretical surfaces are qualitatively the same for values of u_i at all three levels (see Appendix Figures A1a-A1f). Moreover, the potential fourth-order polynomial relationship between FAS_{ij} and k_i is even more evident at the mean of s_i and at $u_i = 0.3$ (see Appendix Figures A1a and A1b).

4.3. Physical Capital, Skilled Labor, and Trade Flows

The empirical KC literature has tended to ignore the "interconnected" relationships predicted for trade flows which, as Blonigen (2005, p. 29) notes, is an important feature of the KC model. "Interconnectedness" between FAS and trade is a potential comparative advantage of a GE approach.[16] Our study addresses this shortcoming. In the following, $Trade_{ij}$ and $Trade_{ij}$ refer to the empirically predicted and theoretically predicted aggregate bilateral exports from country *i* to country *j*, respectively.

In our theoretical model, there are two potential sources of bilateral trade flows from *i* to *j* with

[15]While difficult to see distinctively from Figures 2c and 2d, the underlying numbers from the numerical KAPC model simulation confirm the fourth-order polynomial function for k_i. The theoretical figures for *k-u* space are consistent with previous figures, but omitted for brevity (but available on request). Also, such figures confirm that FAS_{ij} (horizontal or vertical) is a negative monotonic function of u_i, consistent with section 4.1.

[16]By contrast, the *theoretical* KC literature has addressed interconnectedness, cf., Markusen (2002).

regard to good *X*. One source is VMNEs with headquarters in *j* (or *ROW*) and plants in *i*. If *i* is relatively scarce in skilled labor (low s_i) but at least moderately abundant in unskilled labor and physical capital, it has a comparative advantage in producing good *X* and selling it in *i* or exporting it to *j* or *ROW*. The second source of trade from *i* to *j* is exports of national enterprises (NEs) in country *i* with one headquarters and one plant in that country. Since NEs in *i* are one-plant, one-headquarters operations, they will be prominent when *i* is abundant in both physical capital and knowledge capital (for a given u_i), but slightly more abundant in knowledge capital relative to physical capital (since NEs in *i* need to setup up headquarters in *i* whereas VMNEs producing in *i* do not).

Our third set of hypotheses are:

(3a) Exports from country *i* to country *j* will be prominent when country *i* is rich in unskilled labor (relative to knowledge and physical capital), but abundant in *physical capital* relative to knowledge capital, due to VMNEs with plants in *i* but headquarters elsewhere.

(3b) Exports from country *i* to country *j* will be prominent when country *i* is rich in unskilled labor (relative to knowledge and physical capital), but abundant in *knowledge capital* relative to physical capital, due to NEs with headquarters and single plant based in *i*.

(3c) Consequently, our theoretical model suggests that exports from country *i* to country *j* ($Trade_{ij}$) should be a fourth-order polynomial function of country *i*'s share of *i*'s and *j*'s knowledge capital (s_i). However, $Trade_{ij}$ should be only a *second-order* polynomial function of country *i*'s shares of *i*'s and *j*'s physical capital (k_i). $Trade_{ij}$ should be a positive function of unskilled labor, since unskilled labor is important in production for either foreign-based VMNEs' or domestically-based NEs' plants in *i*.

Figure 2e illustrates the theoretically predicted number of VMNEs based in *j* with plants in *i* that can potentially export good *X* from *i* to *j* (as well as to *ROW* or sell in *i*). The figure illustrates the relationships between k_k, s_i, and the numbers of VMNEs based in *j* with plants in *i*, evaluated at the empirical mean of u_i. Since VMNEs have one headquarters plus one plant abroad, VMNEs headquartered in *j* will tend to have plants in *i* and potential exports from *i* to *j* if unskilled (skilled) labor is relatively abundant (scarce) in *i*, since unskilled labor is needed for production and needs to be cheap (relative to skilled labor). Since *j*'s VMNEs (with plants in *i*) would only have one plant in *i*, physical capital need only be moderately abundant in *i*. Hence, Figure 2e shows that VMNEs based in *j* with plants in *i* will be prevalent – and exports from *i* to *j* will be large – when *i* is very scarce in skilled labor and moderately scarce in physical capital (and abundant in unskilled labor).

Figure 2f illustrates the theoretically predicted number of national enterprises (NEs) based in *i* with plants in *i* (and consequently potential NE exports from *i* to *j*). National firms surface in the presence of given trade costs when economies of scale in production can be exploited. For a given level of *i*'s share of *i*'s and *j*'s unskilled labor (u_i) at its mean, national firms surface when both skilled labor and physical capital are abundant, since such firms require these two factors for setups of headquarters and plants, respectively, and when *i* is relatively large economically (in *all* factors) to take advantage of economies of scale in production. However, because NEs in *i* need to setup up headquarters in *i* (which VMNEs headquartered in *j* with plants in *i* do not), NEs will be maximized when *i* is slightly more abundant in knowledge capital relative to physical capital.

Consequently, exports from *i* to *j* will be prevalent when *i* is either very skilled-labor scarce (a comparative advantage for exporting from *i* goods produced by VMNEs headquartered abroad) *or* very skilled-labor abundant (a comparative advantage for exporting from *i* goods produced by NEs headquartered in *i*). Such a contrast in the role for s_i suggests a sharp testable proposition for the relationships between s_i and $Trade_{ij}$. In fact, it suggests – as for FAS – a fourth-order polynomial relationship between s_i and $Trade_{ij}$. To see this, consider Figures 2e and 2f evaluated at $k_i = 0.5$ (and u_i still at its empirical mean), beginning when $s_i = 0$. While difficult to see visually in Figure 2e, the underlying numbers convey that the first inflection point is when s_i is less than 0.225. A second inflection point occurs when $0.225 < s_i < 0.5$. A third inflection point occurs around s_i equal to 0.5. This suggests that $Trade_{ij}$ is a fourth-order polynomial function of s_i, at $k_i = 0.5$ and $u_i = 0.5$.

Figures 2e and 2f suggest that the relationship between $Trade_{ij}$ and *i*'s share of both countries' physical capital stocks (k_i) is ambiguous, and very sensitive to the *level* of s_i. Recall, however, that the empirical mean values of s_i, k_i, and u_i all range between 0.53 to 0.56. At $s_i > 0.5$ (and u_i still at its empirical mean), Figure 2e suggests little relationship between $Trade_{ij}$ and k_i. However, Figure 2f suggests a *second*-order polynomial relationship (or inverse-U shape). Consequently, the polynomial order of the expected relationship is difficult to assess, but our expectation – based upon values of s_i and u_i at their empirical means – is a second-order polynomial relationship.

Finally, we note that the expected relationship between $Trade_{ij}$ and i's share of both countries' unskilled labor (u_i) is positive; more unskilled labor raises a country's comparative advantage in production and consequently in exports. While for brevity we exclude figures in *s-u* and *k-u* space for trade flows, both figures reveal a positive monotonic relationship between $Trade_{ij}$ and u_i. This is opposite of the expected (negative) relationship between FAS_{ij} and u_i discussed earlier, because more unskilled labor reduces a country's comparative advantage in headquartering MNEs.

5. Empirical Framework and Results

As discussed earlier in section 2, several (post-2000) papers have attempted to find empirical evidence of vertical motivations for FAS from cross-country-pair data with expected relationships premised upon the 2-factor, 2-country KC. As CMM (2003) admitted, specifying *ex ante* a "central regression equation" is a difficult task. CMM (2003) even conclude, ". . . there is room for reasonable disagreement as to what the appropriate estimating equation should be" (p. 995).

5.1. Empirical Framework

This paper builds the methodological improvements of two recent papers – BNU (2005) and Bergstrand and Egger (2007) – in order to formulate an "appropriate estimating equation" as conceptually consistent with our theoretical model as possible. The two key methodological improvements from each of these two papers are the following. First, for decades empirical researchers have examined using cross-country-pair (or panel) aggregate bilateral data the economic determinants of FDI or FAS using the "gravity equation." While formal general equilibrium theoretical economic foundations for estimating gravity equations of bilateral *trade* flows have existed for 30 years (cf., Anderson (1979) and Bergstrand (1985)), Bergstrand and Egger (2007) provided the first formal general equilibrium theoretical economic foundation for estimating gravity equations of either bilateral FAS or FDI flows.[17] Moreover, Blonigen and Davies (2004) note that the (log-linear) gravity equation goes a "long way toward generating white noise residuals" in estimating determinants of FDI. Thus, the 3-factor, 3-country, 2-good theoretical framework and empirical evidence in Bergstrand and Egger (2007) provides the starting point for a central regression specification – that is, a gravity equation – to capture economic size and similarity and bilateral trade and investment costs in determining bilateral horizontal FAS and bilateral intra-industry trade.[18] However, Bergstrand and Egger (2007) provide no conceptual guidance on the specification of *relative* factor endowments.

By contrast, BNU (2005) provided three important contributions to empirical investigation of the roles of relative factor endowments for explaining FAS flows in the 2-factor, 2-country KC model. One contribution was to extend empirical analysis from just *U.S.* inward and outward FAS flows to a broad sample of countries; BDH (2003) also contributed here. We follow this suggestion using bilateral FAS data from UNCTAD (country profiles) for 1986-2000 among 36 countries listed in the Data Appendix. Second, BNU measured relative factor endowments of skilled and unskilled labor using factor-share measures implied directly by Edgeworth-box (geometric) considerations. We follow this suggestion as well, and detail in the next paragraph how we adapt it to our 3-factor, 3-country setting. Third, BNU summarized the *empirically*-predicted FAS values (based upon their final regression specification) using an Edgeworth box to confirm visually the "goodness of fit," alongside conventional R^2 measures; we will adopt this in section 5.2.2 and discuss it then.

The second BNU methodological innovation just noted reminds us that a country's factor *shares* measure precisely the "location" of a pair of countries in an Edgeworth box. First, we know from the 2x2x2 KC literature that a traditional 2-dimensional Edgeworth box can be used theoretically to reflect the relationship between s_i, u_i, and, say, bilateral FAS of headquarters country *i* in affiliate country *j*

[17] As noted earlier, the theoretical framework in Bergstrand and Egger (2007) assumed identical *relative* factor endowments between countries to focus on gravity equations of and economic determinants of horizontal FAS and intra-industry trade.

[18] Recall that recent theoretical foundations for the gravity equation are based upon *N*-country worlds, so the *ROW* is taken into account.

(FAS_{ij}), Hence, a regression equation trying to capture the theoretical surfaces relating vertical FAS and horizontal FAS to relative factor endowments implied by the Edgeworth box should include s_i *and* u_i explicitly. Moreover, in a 3-factor setting, we are in an Edgeworth "cube." Hence, to evaluate a *slice* of the cube – say, for a given k_i – the regression must include k_i to hold it constant. Hence, for given absolute endowments, a regression specification for capturing the relationships between FAS_{ij}, s_i, u_i, and k_i should include – on the RHS – s_i, u_i, and k_i explicitly.

Second, a critical assumption of an Edgeworth box is that *absolute* factor endowments are held constant. In the 2-country case, this is accounted for by including the two countries' GDPs, as the gravity equation would suggest; in cross-section, as is well established, the correlation between GDP and absolute factor endowments is very high (so that inclusion of GDP for economic size is sufficient). However, the 3-country methodology of Bergstrand and Egger (2007) suggests that the GDPs of countries *i*, *j*, and *ROW* need to be accounted for. In a large cross section, *ROW* (world) GDP variation is virtually (actually) zero, and so need not be included. In a panel, changes in *ROW* GDP are easily accounted for using time dummies.

Consequently, our regression specifications to explain bilateral FAS and trade flows basically "wed" the methodological contributions of Bergstrand and Egger (2007) – suggesting a standard gravity equation to account for economic size (or absolute factor endowments), trade costs, and investment costs – and of BNU (2005) – suggesting the use of factor shares s_i, u_i, and k_i to account for relative factor endowments. However, before proceeding we note three minor specification caveats. First, a typical gravity equation specifies the log of the empirically-measured flow (here, FAS_{ij} or $Trade_{ij}$) as a function of the log of the product of *i*'s and *j*'s GDPs, where the product of GDPs captures economic size *and* similarity. For instance, it can be shown easily that $GDP_i GDP_j = (GDP_i + GDP_j)^2\{[GDP_i/(GDP_i + GDP_j)][GDP_j/(GDP_i + GDP_j)]\}$, where the term in { } is an index of economic similarity (i.e., it reaches a maximum when $GDP_i = GDP_j$), cf., Bergstrand and Egger (2007). However, in an Edgeworth box, an increase in, say, s_i holding constant u_i (and for some given k_i) changes relative factor endowments *and relative economic sizes* of *i* and *j*. Recall, only along one particular locus will an increase (decrease) in s_i (u_i) change relative factor endowments *but not* relative economic sizes, cf., Markusen (2002).

Consequently, in our regression specification, we will eventually exclude the usual measure of economic similarity, but of course include the log of the sum of GDP_i and GDP_j. Second, typical gravity equation specifications include several variables to capture bilateral trade and/or investment costs. In this regard, we include standard time-invariant bilateral "cost" variables: the log of bilateral distance, a dummy variable for common land border (1 if adjacent, and 0 otherwise), and a dummy variable for common official language (1 if the same, and 0 otherwise). Following Markusen (2002), we also include cross-sectional and time-varying logarithms of multilateral measures of country trade resistance and investment resistance indexes from CMM (2001): TC_i, TC_j, and $INVC_j$. Unfortunately, data constraints preclude bilateral measures, which would be preferable. Third, in the specifications below, we include a time "dummy" for each year (except one, due to the constant) to capture potentially time-varying *ROW* GDP; however, for brevity we do not report the coefficient estimates for the intercept and time dummies.[19]

For estimation, we use a Poisson Quasi-Maximum Likelihood (PQML) approach. The reason for the PQML estimation method is the following. First, because of the multiplicative relationship between levels of flows and their economic determinants and Jensen's inequality, in the presence of heteroskedasticity OLS estimation of log-linearized equations may lead to biased coefficient estimates for RHS variables. The PQML estimation method can address this concern, cf., Santos Silva and Tenreyro (2006). Second, PQML can be applied with dependent variables that include zero and positively-valued observations, such as FAS and trade flows. PQML exploits variation from both zero and non-zero observations, and our theoretical model predicts a large number of zeros and our empirical FAS data set has a large number of zeros. Data sources are listed in the Data Appendix.

5.2. Empirical Results

5.2.1 Regression Results

Table 1 reports various specifications for PQML regressions for bilateral FAS and bilateral trade

---

[19]Regarding other "third-country" effects such as *ROW* trade and investment barriers, these effects are more difficult to capture because any country-specific dummies would preclude cross-section variation in s_i, k_i, and u_i, cf., Anderson and van Wincoop (2003) or Baier and Bergstrand (2009). Moreover, in a panel, such effects would require country-and-time dummies, which would also preclude variation in s_{it}, k_{it}, and u_{it}, cf., Baier and Bergstrand (2007). We leave this issue for researchers to address in the future.

flows. As described above, our specifications begin with a traditional gravity equation, motivated by the 3-factor, 3-country theoretical framework in Bergstrand and Egger (2007); we then incorporate various polynomial functions of s_i, k_i, and u_i. The first two columns in Table 1 provide, respectively, a list of the RHS variables and their expected coefficient signs. The third through ninth columns report coefficient estimates and z-statistics (in parentheses) for specifications 1-7 for explaining bilateral FAS. The tenth and eleventh columns report coefficient estimates and z-statistics for specifications 6 and 7 for explaining bilateral trade flows. We now discuss each in turn.

Specification 1 provides the results of estimating a traditional gravity equation, where RHS variables capture economic size (a proxy for absolute factor endowments) and similarity and various factors that either impede or enhance flows. Recall from earlier, $GDP_iGDP_j = (GDP_i + GDP_j)^2\{[GDP_i/(GDP_i + GDP_j)][GDP_j/(GDP_i + GDP_j)]\}$. Consequently, instead of including the log of the product of two countries' GDPs, we include separately $\log(GDP_i + GDP_j)$ and $\log(Similarity_{ij})$ where $Similarity_{ij} = [GDP_i/(GDP_i + GDP_j)][GDP_j/(GDP_i + GDP_j)]$. Economic size and similarity have the expected positive and statistically significant relationships with FAS_{ij}.The two coefficient estimates suggest a clear "horizontal motivation" for MNE activity, as in Bergstrand and Egger (2007).

We now discuss the other "traditional" gravity-equation variables included in specification 1. As often found, the log of bilateral distance has a negative and statistically significant coefficient and a conventional value throughout all the specifications (and so we will provide no further discussion). Of course, as in the KC literature, actual "distance" has no theoretical role, but is often interpreted as a trade and/or investment "friction" and typically included. We specify the expected sign on Contiguity as ambiguous for FAS_{ij}. The reason is that – if FAS has a horizontal motivation – then FAS is a substitute for trade, and contiguity may have a negative effect (lower trade-costs cause more trade and less FAS). If contiguity reduces information costs, then it may have a positive effect on FAS_{ij}. In all the FAS specifications, Contiguity has a positive and statistically significant effect (so we will provide no further discussion of it). A common language is likely to enhance information flows, and the expected effect is positive; in all the FAS specifications, the coefficient estimate is effectively zero and statistically insignificant. The log of the investment cost index in *j* ($\log(Invc_j)$) is expected to have a negative effect on FAS_{ij}, representing a barrier to either vertical or horizontal investment in *j*. Throughout the FAS specifications, this variable has the expected negative sign and is statistically significant (so we will provide no further discussion of it). Finally, we include two indexes of "trade costs," one multilateral trade-cost index for *j* ($\log(Tc_j)$) and one such index for *i* ($\log(Tc_i)$). For $\log(Tc_j)$, we have no unambiguous sign expectation. The reason is that, if FAS has a horizontal motivation, we would expect a positive coefficient, as FAS and trade are substitutes. However, in reality, even HMNEs based in *i* with plants in *j* require some intermediate inputs from *i*, for which trade costs in *j* would impede FAS_{ij}. It turns out that the coefficient estimates for $\log(Tc_j)$ tend to be effectively zero for most FAS specifications (so we will provide no further discussion of it). Distance may be effectively capturing much of this variable's cross-sectional effect. Finally, the expected coefficient sign for $\log(Tc_i)$ is negative. If FAS_{ij} has a vertical motivation, then we would expect goods to flow from *j* to *i*; trade costs in *i* would diminish these flows. Hence, FAS_{ij} may *indirectly* be reduced because of trade costs in *i*; this creates a negative expected effect. However, the coefficient estimates for $\log(Tc_i)$ are positive and statistically significant for all the FAS specifications, which is unexpected. The overall pseudo-R^2 value for specification 1 is 0.61, which is about the same (0.58) as that for a similar gravity specification for FDI flows in Bergstrand and Egger (2007).

Specification 2 enhances the FAS gravity equation, adding just s_i and u_i to the previous specification. The reason for reporting this specification – even though our theoretical model suggests that s_i should be included as a fourth-order polynomial – is to determine if we can find a similar (positive) effect as for the variables $SKILL_{ij}$ (= s_i/u_i) in BNU (2005) and $SKDIFF_{ij}$ (measured as the difference in *i*'s and *j*'s skilled labor stocks as shares of total labor force) in CMM (2001). We confirm this.[20] Holding u_i constant, s_i has a positive and statistically significant coefficient estimate and – holding s_i constant – u_i has a negative and statistically significant coefficient estimate; this suggests that there is some "vertical motivation" for FAS. Of course, this specification is not motivated by our theoretical Edgeworth boxes and is subject to the same potential specification concern as raised in BDH (2003). However, it is useful

[20]Note that variables s_i, k_i, and u_i are not expressed in logs, so their coefficient estimates are not reflecting "elasticities."

to ascertain that this simple specification "accords" with earlier results of CMM and BNU motivated by the 2-factor, 2-country KC model. Finally, we note that *none* of the other (gravity-equation-motivated) variables' coefficient estimates change materially, and so there remains evidence of "horizontal motivation" for FAS as well.

In specification 3, we consider for the first time the role of relative *physical capital* endowments by adding k_i to the previous specification. Interestingly, the only variable whose coefficient estimate changes materially is *i*'s skilled labor share, s_i. This is interesting because it suggests that measures of relative skilled labor endowments in previous studies may have been effectively a proxy for relative *physical capital* endowments in explaining FAS – which is plausible. Only relative physical capital (k_i) and unskilled labor (u_i) factor endowments – of the three relative endowment variables s_i, k_i, and u_i – are statistically significant.

As noted earlier, the inclusion of variables s_i, k_i, and u_i maps relative factor shares *directly* from the theory. However, also noted earlier, variation in any one variable – such as s_i – for given values of k_i and u_i – necessarily (in an Edgeworth box) changes relative economic *sizes* of *i* and *j*. Thus, one can argue that the change in any one factor share (vertically or horizontally in the box) changes relative factor endowments and economic size, so that the inclusion of log(Similarity$_{ij}$) is inappropriate. By these considerations, we ran specification 4 which differs from previous specification 3 only by the exclusion of log(Similarity$_{ij}$). The important outcome is that the exclusion of log(Similarity$_{ij}$) does *not* create any significant omitted variables bias; none of the other variables' coefficient estimates changes materially. Consequently, in the remaining specifications we exclude log(Similarity$_{ij}$); however, for robustness all subsequent specifications' results are largely insensitive to its absence (and available on request).

Theoretical discussion in section 4.1, theoretical Figures 2a and 2b, and Hypothesis 1c imply that – for given k_i and u_i – FAS$_{ij}$ should be a fourth-order polynomial function of s_i. Specification 5 modifies the previous specification by including s_i, s_i^2, s_i^3, and s_i^4. The expected signs for these four variables' coefficients in specification 5 for a fourth-order polynomial function following the shape suggested by theoretical Figures 2a and 2b at the means of k_i and u_i (about 0.5) are listed in the second column of Table 1. Specification 5 shows that the coefficient estimates have the expected signs and all are statistically significant. Hence, in a comparison of specifications 4 and 5, s_i in specification 4 (without the fourth-order polynomial function) is economically and statistically insignificant but using a fourth-order polynomial, s_i has the expected theoretical relationship with FAS_{ij}. Moreover, *none* of the other variables' coefficient estimates changes materially between specifications 4 and 5. Thus, Hypothesis 1c is confirmed empirically.

Section 4.2, theoretical Figures 2c and 2d, and Hypothesis 2c imply that – for given s_i and u_i – FAS_{ij} should be a fourth-order polynomial function of k_i. Specification 6 modifies the previous specification by including k_i, k_i^2, k_i^3, and k_i^4. The expected signs for these four variables' coefficients in specification 6 for a fourth-order polynomial function following the shape suggested by theoretical Figures 2c and 2d at the means of s_i and u_i (about 0.5) are listed in the second column of Table 1. Specification 6 shows that the coefficient estimates follow a fourth-order polynomial function with coefficient estimate signs corresponding precisely to the expected ones, and all coefficient estimates for these four variables are statistically significant. Moreover, none of the other variables' coefficient estimates changes materially between specification 5 and 6. Thus, Hypothesis 2c is confirmed empirically.

We note across all six FAS specification that u_i has the expected negative coefficient sign with statistical significance. This accords with the intuition that FAS of MNEs based in *i* will be lower the relatively more unskilled labor abundant *i* is, because unskilled labor raises its comparative advantage in production over headquarters. Theoretical Figures 2a and 2b suggest a monotonic negative relationship between FAS_{ij} and u_i.

Even though the fourth-order polynomial functions for s_i and k_i captured the theoretical relationships in Edgeworth-box space, we were curious to see if specification 6's results were sensitive to *interaction* terms, commonly used in the KC literature. While many interaction terms are possible, we considered adding only the interaction terms s_ik_i, s_iu_i, and k_iu_i – that is, interactions among the key factor-share variables. For FAS, there are no clear unambiguous predictions for s_iu_i and s_ik_i; this is shown easily by re-examining Figures 2a-2d for s_iu_i and s_ik_i, respectively. In Figures 2a and 2b, $HMNE_{ij}$ activity peaks when s_i and u_i are both low (suggesting a possible positive coefficient estimate for s_iu_i) but $VMNE_{ij}$ peaks when s_i is high but u_i is low (suggesting a possible negative coefficient estimate for s_iu_i). In Figures 2c and 2d, a similar ambiguous prediction for the coefficient of s_ik_i exists. Specification 7 reports the results of adding these interaction terms. Interestingly, none of the coefficient estimates of the interaction terms was statistically significantly different from zero. Moreover, their inclusion had no material impact on the other coefficient estimates.

Finally, specifications 8 and 9 provide the results for estimating the same specifications for Trade_{ij} as for FAS_{ij} in specifications 6 and 7, respectively. Section 4.3, theoretical Figures 2e and 2f, and Hypothesis 3c imply that – for given k_i and u_i at their empirical means – Trade_{ij} should be a fourth-order polynomial function of s_i and – for given s_i and u_i at their empirical means – Trade_{ij} should be a *second-order* polynomial function of k_i. As noted specification 8 uses for Trade_{ij} the same formulation as specification 6 for FAS_{ij}; however, theory suggested that we should expect a second-order – not fourth-order – polynomial function for k_i. Consequently, we do *not* expect all the coefficient estimates for the four terms of k_i to be statistically significant. Specification 8 reports that Trade_{ij} is, in fact, a fourth-order polynomial function of s_i *but* a second-order polynomial function of k_i! The coefficient estimate of k_i^2 (5.63) is statistically insignificant. A graph of the function $f(k_i) = 6.12\, k_i - 25.10\, k_i^3 + 13.84\, k_i^4$ is an "inverse-U-shaped" (quadratic) function, likely reflecting that the number of national exporters (NEs) is a hump-shaped function of k_i. Thus, Hypothesis 3c is confirmed empirically.

For completeness, specification 9 is the same specification for Trade_{ij} as specification 7 – with three factor-share interaction terms – as for FAS_{ij}. Unlike for FAS_{ij}, in this case, two of the three interaction terms are statistically significant, eroding the statistical significance of the coefficient estimates of the two higher-order terms k_i^3 and k_i^4 in specification 8. However, the coefficient estimates for k_i^3 and k_i^4 in specification 9 are only slightly lower (in absolute terms) than the corresponding ones in specification 8. While a full analysis of all the marginal effects implied by specification 9 are beyond the scope of this already lengthy paper, we note one important finding that we can explain using our theoretical Figures 2e and 2f. The coefficient estimate for the interaction term between s_i and k_i (s_ik_i) is positive and statistically significant. As theoretical Figure 2f suggests, $Trade_{ij}$ should be high when s_i and k_i are both high. Note that none of the other variables' coefficient estimates in specification 9 change materially from the corresponding ones in specification 8.

5.2.2 Empirically-Predicted FAS and Trade Flows

The previous section provided empirical evidence using conventional econometric techniques confirming Hypotheses 1c, 2c, and 3c regarding the Edgeworth-box surfaces describing the relationships between relative factor shares, vertical MNE activity, horizontal MNE activity, and bilateral trade. However, Hypotheses 1a, 1b, 2a, 2b, 3a, and 3b are very specific about where in Edgeworth box the numbers of VMNEs and HMNEs with headquarters in *i* and plants in *j* will be maximized and where bilateral trade from plants in *i* of NEs based in *i* and of VMNEs with headquarters in *j* will be maximized. In this section, we draw upon one of the innovations in BNU (2005) – which employed the *empirically-predicted* bilateral FAS flows using its central regression equation – to examine the similarity of the Edgeworth boxes using the theoretically-predicted numbers of VMNEs, HMNEs, and NEs and those using empirically-predicted FAS_{ij} and $Trade_{ij}$. Such a methodology introduced by BNU is new to the MNE literature. Moreover, we must extend this approach in our 3-factor setting to *slices* of an Edgeworth "cube," evaluating the Edgeworth slices at the empirical means of the (implicit) third factor. It is important to recall that the empirical means for s_i, k_i, and u_i all lie between 0.53-0.56; hence, for simplicity, we can essentially consider the mean of each as 0.5.

Figure 3a provides the Edgeworth box relating empirically-predicted FAS_{ij} to s_i and u_i at the empirical mean of k_i. This figure corresponds to theoretical Figures 2a and 2b. First, note that the surface in Figure 3a confirms Hypotheses 1a, 1b, and 1c. Predicted (empirical) FAS_{ij} reaches one of two maxima when skilled labor is very abundant relative to unskilled labor in *i*, similar to the KC model. Using theoretical Figure 2b, we interpret this FAS as *vertical*. Second, note that predicted FAS_{ij} reaches a second of two maxima when *i*'s skilled labor is *modestly* abundant relative to unskilled labor and *i* is economically small relative to *j*. Using theoretical Figure 2a, we interpret this FAS as *horizontal*. The two main conclusions from Figure 3a are that, in the context of the theoretical model, both horizontal *and* vertical FAS are important (with HMNE activity slightly more important empirically) and each type of FAS attains its maximum in the Edgeworth box where Figures 2a and 2b predict! Thus, Figure 3a is consistent with Hypotheses 1a-1c.

Figure 3b provides the Edgeworth box relating empircally-predicted FAS_{ij} to k_i and s_i at the empirical mean of u_i and provides empirical support for the *main economic insight* of this paper. This figure corresponds to theoretical Figures 2c and 2d. Predicted (empirical) FAS_{ij} reaches a maximum when either country *i* is abundant in knowledge capital *and* physical capital relative to unskilled labor – which favors VMNE activity over HMNE activity (see theoretical Figure 2d) – ***or*** country *i* is abundant in physical capital *relative to* knowledge capital – which favors HMNE activity over VMNE activity (see theoretical Figure 2c). Figure 3b confirms empirically that both horizontal and vertical FAS are important (with HMNE activity slightly more important empirically) and each type of FAS attains its maximum in the Edgeworth box where Figures 2c and 2d predict. Figure 3b is consistent with Hypotheses 2a-2c.

Finally, due to the "interconnectedness" of FAS and trade in the KAPC model, we can also compare the relationships between empirically-predicted $Trade_{ij}$ from specification 8 and factor shares; for brevity, we discuss only the relationships between $Trade_{ij}$, k_i, and s_i at the empirical mean of u_i. Figure 3c provides the Edgeworth box relating predicted $Trade_{ij}$ to k_i and s_i at the empirical mean of u_i and provides further empirical support for vertical motivation for FAS. This figure corresponds to theoretical Figures 2e and 2f. First, note that the surface in Figure 3c is consistent with Hypothesis 3a. Predicted (empirical) $Trade_{ij}$ attains one of two maxima when country *i* is abundant in physical capital *relative to* knowledge capital. Using theoretical Figure 2e, we interpret the source of this trade as vertical MNEs with headquarters in *j* but plants in *i* that can export goods back from *i* to *j*. Second, note that we can differentiate the VMNE source of $Trade_{ij}$ from exports of NEs based in *i* that export from *i* to *j*. Using theoretical Figure 2f, we can interpret the other maximum of Figure 3c as trade flows of NEs based in *i*. This confirms Hypothesis 3b, that exports from *i* to *j* will be at a maximum also when *i* is abundant in knowledge capital *relative to* physical capital, due to national exporting firms in *i*. Figure 3c is consistent with Hypotheses 3a-3c.

6. Conclusions

In contrast to Thomas Friedman's claim that "the world is flat" partly due to FDI from developed to developing countries, Blonigen's (2005) survey of empirical research on determinants of FDI notes that international economists have found little convincing empirical support for the "vertical motivations" in Friedman's claims that relative factor endowments explain significantly foreign affiliate production and sales for multinational enterprises. This paper has offered an alternative approach to try to better understand empirically and theoretically the relationships between MNE's *bilateral aggregate* foreign affiliate sales (FAS) and countries' relative factor endowments. By extending the KC model with only skilled and unskilled labor to include a third, internationally-mobile factor (physical capital) and a third country (*ROW*), we could explain theoretically the complex, nonlinear, nonmonotonic empirical relationships between bilateral FAS flows of two countries and their relative endowments of skilled labor, unskilled labor, *and* physical capital. Moreover, we showed that the theoretical trade flows implied *simultaneously* by our Knowledge-and-Physical-Capital model could also explain the (predicted) empirical bilateral trade flows of the same countries. An important conclusion is that the data-generating process for both empirical FAS and trade flow volumes can be explained by a *common* theoretical framework. Our empirical evidence suggests that both horizontal *and vertical* motivations for FAS exist – and physical capital matters in the explanation.

Data Appendix

Bilateral trade flow data are from the UN World Trade Database for 1990-2000. Bilateral foreign affiliate sales data are from UNCTAD (country profiles) for 1986-2000. GDPs are from the World Bank's *World Development Indicators* (2004). Nominal export data in U.S. dollars have been deflated using producer price indices (base year 2000) of the exporter country (taken from the *World Development Indicators*). Similarly, we followed Carr, Markusen, and Maskus (2001) by deflating nominal foreign affiliate sales in U.S. dollars by host country producer price indices. Physical capital stocks are computed by using the perpetual inventory method following Leamer (1984), using gross fixed capital formation and investment deflator data from the World Development Indicators and assuming a depreciation rate of 13.3 percent. Data on human capital endowments were kindly provided by Scott Baier and are based on information in the *World Development Indicators* on school enrollment (see Baier, Dwyer, and Tamura, 2006). Remaining workers are classified as unskilled. Bilateral distance was computed using "great circle" distances. The country trade resistance and investment resistance indexes are from Carr, Markusen, and Maskus (2001), kindly provided by Keith Maskus.

The exporting (FAS parent) and importing (host) countries include the following: Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, Colombia, Denmark, Egypt (imports/FAS host only), Finland, France, Germany, Greece, Hong Kong, Ireland, Israel, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Philippines, Portugal, Singapore, South Africa, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States, United Kingdom, and Venezuela.

References

Alfaro, Laura, and Charlton, Andrew. "Intra-Industry Foreign Direct Investment." National Bureau of Economic Research Working Paper No. 13447, September 2007.

Anderson, James E. "A Theoretical Foundation for the Gravity Equation." *American Economic Review* 69, no. 1, March 1979:106-116.

Anderson, James E., and van Wincoop, Eric. "Gravity with Gravitas: A Solution to the Border Puzzle." *American Economic Review* 93, no. 1, March 2003: 170-192.

Baier, Scott, Dwyer, Gerald, and Tamura, Robert. "How Important are Capital and Total Factor Productivity for Economic Growth?" *Economic Inquiry* 44, no. 1, January 2006: 23-49.

Baier, Scott L., and Bergstrand, Jeffrey H. "Do Free Trade Agreements Actually Increase Members' International Trade?" *Journal of International Economics* 71, no. 1, March 2007: 72-95.

Baier, Scott L., and Bergstrand, Jeffrey H. "*Bonus Vetus* OLS: A Simple Method for Approximating International Trade-Cost Effects using the Gravity Equation." *Journal of International Economics* 77, no. 1, February 2009: 77-85.

Barba Navaretti, G., and Venables, Anthony J. *Multinational Firms in the World Economy*, Princeton, NJ: Princeton University Press, 2004.

Bergstrand, Jeffrey H. "The Gravity Equation in International Trade: Some Microeconomic Foundations and Empirical Evidence." *Review of Economics and Statistics* 67, no. 3, August 1985, 474-481.

Bergstrand, Jeffrey H., and Egger, Peter. "Trade Costs and Intra-Industry Trade." *Review of World Economics* 142, no. 3, 2006: 433-458.

Bergstrand, Jeffrey H., and Egger, Peter. "A Knowledge-and-Physical-Capital Model of International Trade Flows, Foreign Direct Investment, and Multinational Enterprises." *Journal of International Economics* 73, no. 2, November 2007: 278-308

Bernhard, Andrew B., Jensen, J. Bradford, and Schott, Peter K. "Importers, Exporters, and Multinationals: A Portrait of Firms in the U.S. that Trade Goods." Tuck School of Business at Dartmouth Working Paper No. 2005-17, May 2005.

Blonigen, Bruce A. "A Review of the Empirical Literature on FDI Determinants." *Atlantic Economic Journal* 33, 2005: 383-403.

Blonigen, Bruce A., and Davies, Ronald B. "The Effects of Bilateral Tax Treaties on US FDI Activity." *International Tax and Public Finance* 11, no. 5, 2004, 601-622.

Blonigen, Bruce A., Davies, Ronald B., and Head, Keith. "Estimating the Knowledge-Capital Model of the Multinational Enterprise: Comment." *American Economic Review* 93, no. 3, June 2003, 980-994.

Borga, Maria, and Yorgason, Daniel R. "Direct Investment Positions for 2001: Country and Industry Detail." *Survey of Current Business*, July 2002: 25-35.

Braconier, Henrik, Norbäck, Pehr-Johan, and Urban, Dieter. "Reconciling the Evidence on the Knowledge-Capital Model." *Review of International Economics* 13, no. 4, September 2005: 770-786.

Brainard, Lael S. "An Empirical Assessment of the Proximity-Concentration Trade-off Between Multinational Sales and Trade." *American Economic Review* 87, no. 4, September 1997, 520-544.

Carr, David, Markusen, James R., and Maskus, Keith E. "Estimating the Knowledge-Capital Model of the Multinational Enterprise." *American Economic Review* 91, no. 3, June 2001, 693-708.

Carr, David, Markusen, James R., and Maskus, Keith E. "Estimating the Knowledge-Capital Model of the Multinational Enterprise: Reply." *American Economic Review* 93, no. 3, June 2003, 995-1001.

Davies, Ronald B. "Hunting High and Low for Vertical FDI." *Review of International Economics* 16, no. 2, May 2008, 250-267.

Ekholm, Karolina, Forslid, Rikard, and Markusen, James R. "Export-Platform Foreign Direct Investment." *Journal of the European Economic Association* 5, no. 4, 2007, 776-795.

Feenstra, Robert C. "New Product Varieties and the Measurement of International Prices." *American Economic Review* 84, no. 1, March 1994, 157-177.

Friedman, Thomas. *The World is Flat.* New York: Farrar, Strauss, and Giroux, 2005.

Goldin, Claudia, and Katz, Lawrence. "The Origins of Technology-Skill Complementarity." *Quarterly Journal of Economics* 113, no. 3, 1998: 693-732.

Griliches, Z. "Capital-Skill Complementarity." *Review of Economics and Statistics* 51, 4, November 1969, 465-468.

Head, Keith, and Ries, John. "Increasing Returns Versus National Product Differentiation as an Explanation for the Pattern of U.S-Canada Trade." *American Economic Review* 91, no. 4, September 2001, 858-876.

Helpman, Elhanan. "A Simple Theory of International Trade with Multinational Corporations." *Journal of Political Economy* 92, no. 3, June 1984, 451-471.

Helpman, Elhanan. "Trade, FDI, and the Organization of Firms." *Journal of Economic Literature* 94, no. 3, September 2006: 589-630.

Helpman, Elhanan, and Razin, Assaf. "Increasing Returns, Monopolistic Competition, and Factor Movements." *Journal of International Economics* 14, 1983: 263-276.

Jones, Ronald W. "International Capital Movements and the Theory of Tariffs and Trade." *Quarterly*

Journal of Economics 81, no. 1, February 1967: 1-38.

Markusen, James R. "Multinationals, Multi-Plant Economies, and the Gains from Trade." *Journal of International Economics* 16, 1984, 206-226.

Markusen, James R. *Multinational Firms and the Theory of International Trade*. Cambridge, MA: MIT Press, 2002.

Markusen, James R., and Maskus, Keith E. "Multinational Firms: Reconciling Theory and Evidence." In *Topics in Empirical International Economics: A Festschrift in Honor of Robert E. Lipsey,* edited by Magnus Blomstrom and Linda Goldberg, 2001, Chicago: University of Chicago Press.

Markusen, James R., and Maskus, Keith E. "Discriminating Among Alternative Theories of the Multinational Enterprise." *Review of International Economics* 10, no. 4, November 2002, 694-707.

Markusen, James R.; Venables, Anthony J.; Eby-Konan, Denise; Honglin Zhang, Kevin. "A Unified Treatment of Horizontal Direct Investment, Vertical Direct Investment and the Pattern of Trade in Goods and Services," NBER Working Paper No. 5696, 1996.

Mundell, Robert. "International Trade and Factor Mobility. *American Economic Review* 47, no. 3, 1957: 321-335.

Santos Silva, J.M.C., and Tenreyro, Silvana . "The Log of Gravity." *Review of Economics and Statistics* 88, no. 4, September 2006, 641-658.

Slaughter, Matthew J. "Production Transfer withing Multinational Enterprises and American Wages." *Journal of International Economics* 50, no. 2, April 2000, 449-472.

Figure 1a

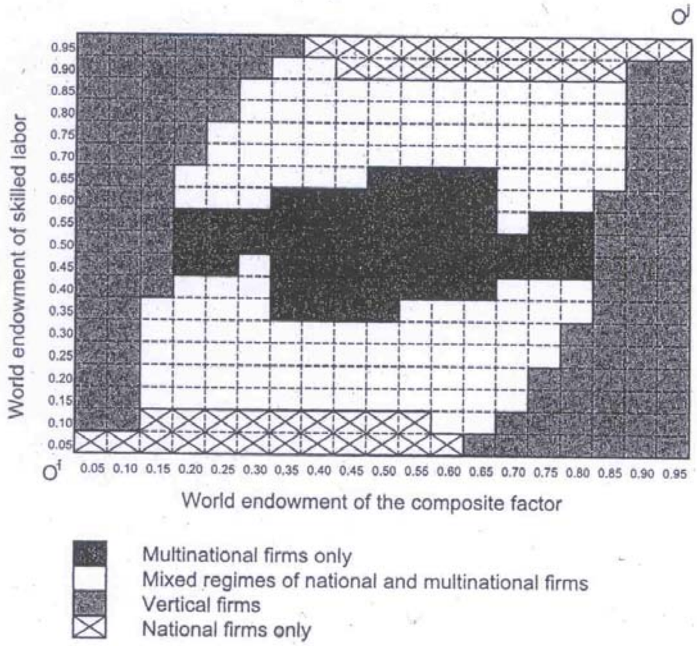


Figure 1b

Types of firms active in equilibrium: Regime (the number in the cell) = $I_i^d + I_j^d + I_i^v + I_j^v + I_i^h + I_j^h$ (I is for "indicator")

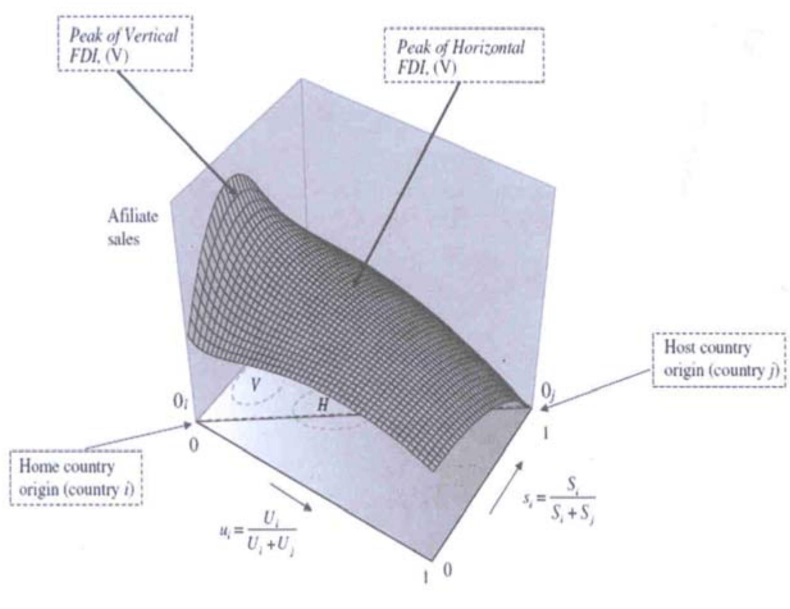
102.000	102.000	102.000	102.000	102.000	102.000	102.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
102.000	102.000	102.000	102.000	102.010	102.010	100.010	100.010	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.200	100.200
102.000	102.000	102.000	102.010	102.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.011	100.001	100.001	100.200	100.200
102.000	102.000	102.010	102.010	102.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.011	100.001	100.001	100.201	100.200
102.000	102.010	102.010	102.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.001	100.001	100.001	100.201	100.200
102.000	102.010	102.010	102.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.010	100.011	100.001	100.001	100.001	0.201	0.200
102.000	102.010	102.010	100.010	100.010	100.010	100.010	100.010	100.010	0.010	0.010	0.010	0.011	100.011	100.001	100.001	100.001	0.201	0.200
102.010	102.010	102.010	100.010	100.010	100.010	0.010	0.010	0.010	0.010	0.011	0.011	0.011	100.011	100.001	100.001	0.201	0.201	0.201
2.010	2.010	102.010	0.010	0.010	0.010	0.010	0.010	0.011	0.011	0.011	0.011	0.011	100.001	0.001	0.001	0.201	0.201	0.201
2.010	2.010	2.010	0.010	0.010	0.010	0.010	0.011	0.011	0.011	0.011	0.011	0.001	0.001	0.001	0.001	0.201	0.201	0.201
2.010	2.010	2.010	0.010	0.010	10.010	0.011	0.011	0.011	0.011	0.011	0.001	0.001	0.001	0.001	0.001	10.201	0.201	0.201
2.010	2.010	2.010	10.010	10.010	10.011	0.011	0.011	0.011	0.001	0.001	0.001	0.001	10.001	10.001	10.001	10.201	10.201	10.201
2.000	2.010	10.010	10.010	10.010	10.011	0.011	0.001	0.001	0.001	10.001	10.001	10.001	10.001	10.001	10.001	10.201	10.201	10.200
2.000	12.010	10.010	10.010	10.010	10.011	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.201	10.201	10.201	10.200
12.000	12.010	10.010	10.010	10.010	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.201	10.201	10.201	10.200
12.000	12.010	10.010	10.010	10.011	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.201	10.201	10.201	10.200	10.200
12.000	12.000	10.010	10.010	10.011	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.001	10.201	10.201	10.200	10.200	10.200
12.000	12.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.001	10.001	10.201	10.201	10.200	10.200	10.200	10.200
10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.200	10.200	10.200	10.200	10.200	10.200	10.200

I_i^d = 100 if type-d_i firms active, 0 otherwise
I_j^d = 10 if type-d_j firms active, 0 otherwise

I_i^v = 2.0 if type-v_i firms active, 0 otherwise
I_j^v = 0.2 if type-v_j firms active, 0 otherwise

I_i^h = 0.01 if type-h_i firms active, 0 otherwise
I_j^h = 0.001 if type-h_j firms active, 0 otherwise

Figure 1c



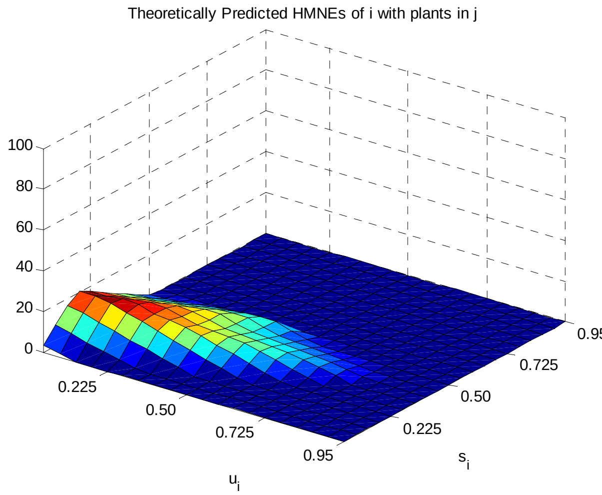


Figure 2a: Mean of k_i

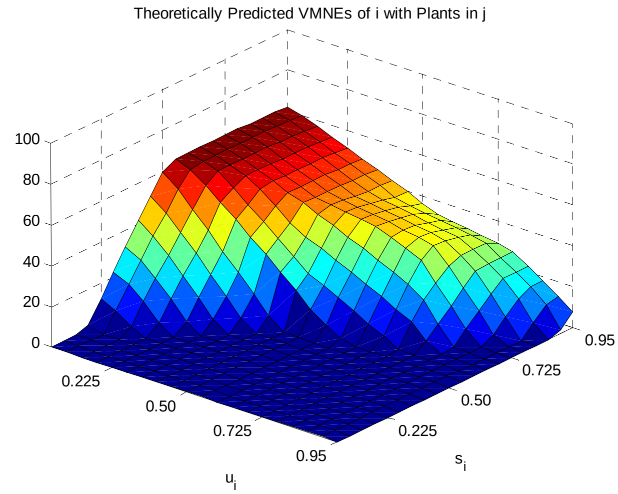


Figure 2b: Mean of k_i

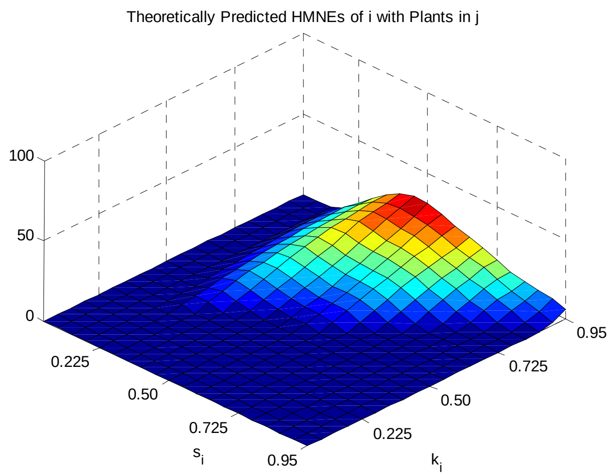


Figure 2c: Mean of u_i

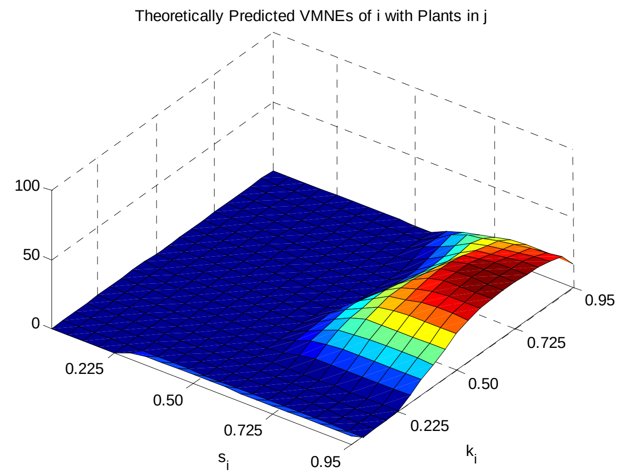


Figure 2d: Mean of u_i

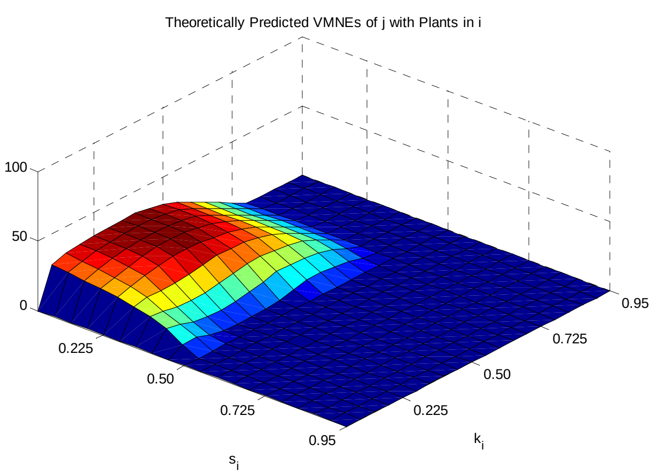


Figure 2e: Mean of u_i

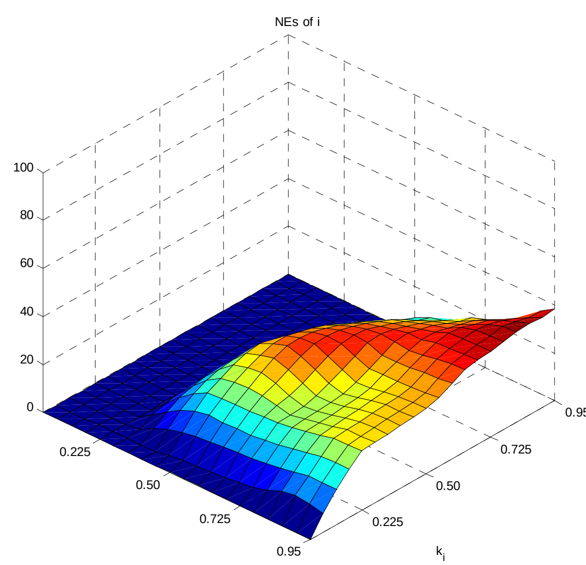


Figure 2f: Mean of u_i

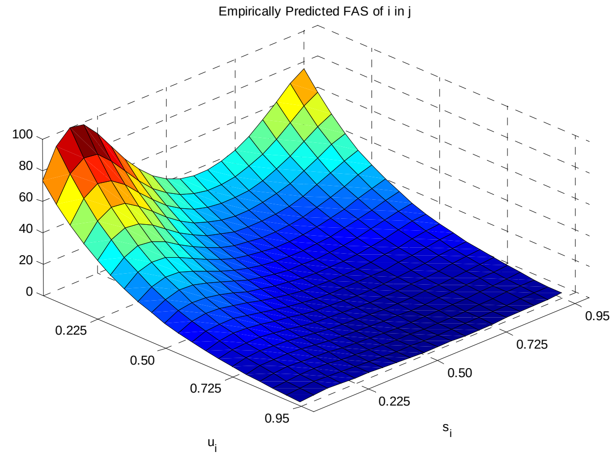


Figure 3a: Mean of k_i

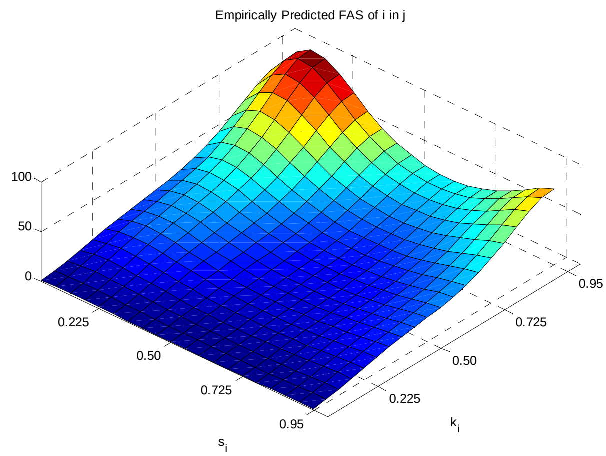


Figure 3b: Mean of u_i

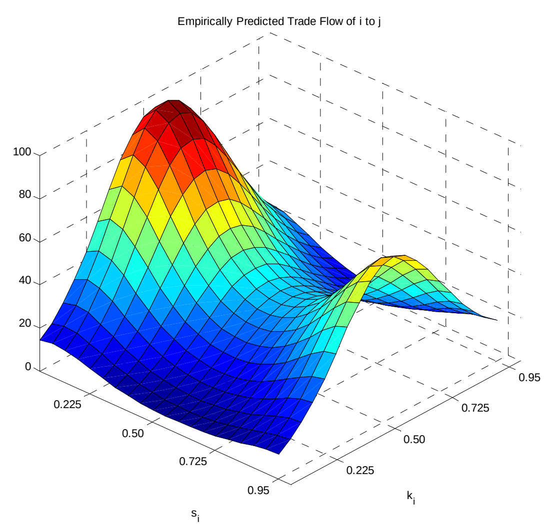


Figure 3c: Mean of u_i

TABLE 1

Bilateral FAS and Trade Flow PQML Regressions

Variables	Expected Sign	FAS (1)	FAS (2)	FAS (3)	FAS (4)	FAS (5)	FAS (6)	FAS (7)	Trade (8)	Trade (9)
$\log(GDP_i+GDP_j)$	+	2.08* (20.21)	2.07* (19.71)	2.06* (19.69)	2.19* (22.76)	2.10* (20.03)	2.33* (19.86)	2.36* (18.35)	1.67* (31.30)	1.71* (24.72)
$\log(Similarity_{ij})$	+	0.13* (2.36)	0.17* (2.72)	0.16* (2.46)						
$\log(Distance_{ij})$	—	-0.70* (-15.41)	-0.67* (-15.41)	-0.67* (-14.27)	-0.69* (-14.88)	-0.66* (-15.30)	-0.64* (-14.94)	-0.61* (-13.98)	-0.63* (-36.99)	-0.63* (-31.66)
Contiguity	? (FAS) + (Trade)	0.25* (2.61)	0.27* (2.84)	0.35* (3.11)	0.36* (3.08)	0.33* (2.97)	0.27* (2.40)	0.25* (2.23)	0.05 (0.99)	0.06 (1.28)
Language	+	0.02 (0.13)	0.03 (0.21)	-0.00 (-0.00)	-0.03 (-0.21)	0.11 (1.01)	-0.07 (-0.68)	-0.06 (-0.55)	0.10* (2.02)	0.15* (2.97)
$\log(Invc_j)$	— (FAS) + (Trade)	-0.69* (-5.37)	-0.69* (-5.35)	-0.92* (-6.85)	-0.84* (-6.12)	-0.86* (-6.78)	-0.85 (-6.56)	-0.79* (-6.01)	-0.02 (-0.24)	-0.11 (-1.69)
$\log(Tc_j)$	? (FAS) — (Trade)	-0.03 (-0.31)	-0.14 (-1.57)	-0.10 (-1.20)	-0.11 (-1.35)	-0.19* (-2.24)	-0.14 (-1.62)	-0.12 (-1.31)	0.09* (1.98)	0.06 (1.23)
$\log(Tc_i)$	— (FAS) 0 (Trade)	0.59* (6.23)	0.74* (7.42)	0.67* (6.46)	0.54* (5.40)	0.62* (6.71)	0.56* (6.15)	0.57* (6.42)	0.07 (1.74)	0.01 (0.19)
s_i	+		0.93* (2.89)	0.32 (0.88)	0.02 (0.06)	26.63* (7.69)	11.83* (2.92)	9.90* (2.26)	6.47* (3.86)	4.38* (2.46)
s_i^2	—					-89.37* (-6.40)	-55.65* (-3.64)	-43.90* (-2.87)	-42.31* (-6.58)	-33.77* (-5.21)
s_i^3	+					113.89* (5.56)	80.86* (3.55)	52.07* (2.13)	69.62* (7.12)	56.98 (5.48)
s_i^4	—					-49.23* (-4.93)	-36.61* (-3.27)	-21.74 (-1.79)	-34.02* (-6.94)	-27.93* (-5.33)
k_i	+			2.39* (5.77)	2.48* (5.68)	3.06* (6.95)	24.93* (6.77)	29.25* (7.36)	6.12* (4.03)	5.92* (3.05)
k_i^2	—						-67.71* (-4.86)	-93.09* (-5.26)	5.63 (0.97)	-3.33 (-0.42)
k_i^3	+						85.72* (4.21)	118.67* (5.04)	-25.10* (-2.90)	-15.80 (-1.38)
k_i^4	—						-38.34* (-3.96)	-54.87* (-4.80)	13.84* (3.23)	9.47 (1.67)
u_i	— (FAS) + (Trade)		-0.97* (-3.18)	-2.98* (-7.30)	-2.87* (-6.63)	-3.79* (-8.95)	-3.73* (-9.00)	-5.19* (-6.07)	0.39* (2.13)	2.21* (5.29)
s_ik_i	? (FAS) + (Trade)							7.95 (1.22)		6.34* (2.85)
s_iu_i	?							0.41 (0.08)		-6.38* (-2.86)
k_iu_i	?							1.92 (0.43)		2.52 (1.46)
No. of Observ. Pseudo R^2		1370 0.61	1370 0.61	1370 0.63	1370 0.63	1370 0.66	1370 0.67	1370 0.67	1152 0.87	1152 0.87

Note: *denotes statistically significant at 5 percent in two-tailed z-test. Numbers in parentheses are z-statistics. Coefficient estimates for the constant and time dummies are not presented for brevity.

Appendix A: Theoretical Model
[NOT INTENDED FOR PUBLICATION]

A.1. Consumers

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 ($\sigma \equiv 1\text{-}\varepsilon$, $\varepsilon < 0$). Manufactures can be produced by three different firm types: national firms (n), horizontal multinational firms (h), and vertical multinational 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 (1) below:

$$V_i = \left[\begin{array}{l} \sum_{j=1}^{3} n_j \left(\frac{x_{ji}^n}{t_{Xji}} \right)^{\frac{\varepsilon}{\varepsilon-1}} + \left(\sum_{j=1}^{3} h_{3,j} (x_{ii}^{h_3})^{\frac{\varepsilon}{\varepsilon-1}} + \sum_{j \neq i} h_{2,ij} (x_{ii}^{h_2})^{\frac{\varepsilon}{\varepsilon-1}} + \sum_{j \neq i} h_{2,ji} (x_{ii}^{h_2})^{\frac{\varepsilon}{\varepsilon-1}} \right) \\ + \sum_{m \neq j} \sum_{j=1}^{3} v_{mj} \left(\frac{x_{ji}^v}{t_{Xji}} \right)^{\frac{\varepsilon}{\varepsilon-1}} \end{array} \right]^{\frac{\varepsilon-1}{\varepsilon}\eta} \left[\sum_{j=1}^{3} Y_{ji} \right]^{1-\eta} \qquad (1)$$

The first component reflects *national* (non-MNE) firms that can produce final differentiated goods for the home market or export to foreign markets from a single plant in the country with its 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 t_{Xji} is the gross trade cost of exporting X from j to i.

The second set of components reflects *horizontal* multinational firms 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 inadequate to warrant a local plant, and is more efficiently served (given trade and investment costs) by its own national firms and imports from foreign firms; this is one feature that extends the model in Bergstrand and Egger (2007), but is inconsequential in the calibration.

The third component reflects *vertical* multinational firms. 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_{mj} denote the number of vertical multinational firms with headquarters in m, a plant in j, and output can be sold to any country (including m). Let x^v_{ji} denote the output of the representative VMNE with production in j and consumption in i. In Bergstrand and Egger (2007), in equilibrium VMNEs did not surface; they will here due to differences in relative factor endowments.

In the second bracketed RHS term, let Y_{ji} denote the output of the homogenous (e.g., agriculture) good produced in country j under constant returns to scale using unskilled labor and consumed in i.

We let t_{Xji} (t_{Yji}) denote the gross trade cost for shipping final differentiated (homogeneous) good X (Y) from j to i.[21] Let $t_{Xji} = 1$ for $i = j$, and analogously for t_{Yji}. It will be useful to define:

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

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 percent) on imports from j to i in differentiated final good X.

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

$$\sum_{j=i}^{3} n_j p^n_{Xj} x^n_{ji} + \sum_{j=i}^{3} h_{3,j} p^{h_3}_{Xi} x^{h_3}_{ii} + \sum_{j\neq i} h_{2,ij} p^{h_2}_{Xi} x^{h_2}_{ii} + \sum_{j\neq i} h_{2,ji} p^{h_2}_{Xi} x^{h_2}_{ii} + \sum_{m\neq j}\sum_{j\neq i} v_{mj} p^v_{Xj} x^v_{ji} + \sum_{j=i}^{3} p_{Yj} Y_{ji}$$
$$= r_i K_i + w_{Si} S_i + w_{Ui} U_i + \sum_{j\neq i} n_j b_{Xji} p^n_{Xj} x^n_{ji} + \sum_{k\neq j}\sum_{j\neq i} v_{kj} b_{Xji} p^v_{Xj} x^v_{ji} + \sum_{j\neq i} b_{Yji} p_{Yj} Y_{ji} \tag{2}$$

where p^{h3}_{Xi} (p^{h2}_{Xi}) denotes the price charged by the representative 3-country (2-country) HMNE with a plant in i. Let p^n_{Xj}, p^v_{Xj}, and p_{Yj} denote the prices charged by producers in j for goods X (national firms and VMNEs, respectively) and Y, respectively. In the second line of equation (2), the first three RHS terms denote factor income; the last three RHS terms 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 (which can be used at home or transferred abroad at a cost in units of capital of γ), w_{Si} (w_{Ui}) is the wage rate for skilled (unskilled) workers in i, and S_i (U_i) is the stock of internationally-immobile skilled (unskilled) workers in i.

Maximizing (1) subject to (2) yields the domestic demand functions:

$$x^{\ell}_{ii} \geq \left(p^{\ell}_{Xi}\right)^{\varepsilon-1} P^{-\varepsilon}_{Xi} \eta E_i; \quad \ell = \left\{n, h_3, h_2, v\right\} \tag{3}$$

where E_i is the income (and expenditure) of the representative consumer in country i from eq. (2), and

$$P_{Xi} = \left[\sum_{j=1}^{3} n_j \left(t_{Xji} p^n_{Xj}\right)^{\varepsilon} + \sum_{j=1}^{3} h_{3,j}\left(p^{h_3}_{Xi}\right)^{\varepsilon} + \sum_{j\neq i} h_{2,ij}\left(p^{h_2}_{Xi}\right)^{\varepsilon} + \sum_{j\neq i} h_{2,ji}\left(p^{h_2}_{Xi}\right)^{\varepsilon} + \sum_{m\neq j}\sum_{j=1}^{3} v_{mj}\left(t_{Xji} p^v_{Xj}\right)^{\varepsilon}\right]^{\frac{1}{\varepsilon}} \tag{4}$$

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

---

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

conditions (cf., 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:

$$\frac{x_{ji}}{x_{ii}} = \left(\frac{p_{Xj}}{p_{Xi}}\right)^{\varepsilon-1} t_{Xji}^{\varepsilon}(1+b_{Xji})^{-1} \tag{5}$$

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:

$$\sum_{j=1}^{3} Y_{ji} \geq \frac{1-\eta}{p_{Yi}} E_i \tag{6}$$

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

A.2. Differentiated Goods Producers

We assume that manufactures can be produced in all three countries, using skilled labor, unskilled labor, and physical capital. Each country is assumed to be endowed with exogenous amounts of internationally immobile skilled labor and unskilled labor. Each country is assumed to be endowed with an exogenous amount of physical capital; however, physical capital can be transferred endogenously across countries by MNEs to maximize their profits, thus making endogenous the determination of bilateral FDI flows. Differentiated goods producers operate in monopolistically competitive markets, similar to Markusen (2002, Ch. 6). Two assumptions used for our theoretical results that follow are the existence of a third, internationally mobile factor – physical capital – *and* that any headquarters setup (fixed cost) requires home skilled labor – to represent R&D – and any plant setup requires the home country's physical capital – to represent the resources needed for a domestic or foreign direct investment.[22]

Assume the production of differentiated good *X* is given by a nested Cobb-Douglas-CES technology where F_{Xi} denotes production of these goods for both the domestic and foreign markets; we assume MNEs and NEs have access to the same technology. Let K_{Xi}, S_{Xi}, and U_{Xi} denote the quantities used of physical capital, skilled labor, and unskilled labor, respectively, in country *i* to produce *X*:

$$F_{Xi} = B(K_{Xi}^{\chi} + S_{Xi}^{\chi})^{\frac{\alpha}{\chi}} U_{Xi}^{1-\alpha} \tag{7}$$

The specific form of the production function is motivated by two literatures. First, the Cobb-Douglas function provides a standard, tractable, and empirically relevant method of combining capital and labor; α denotes the share of "capital" in production. Second, early work by Griliches (1969) indicates that physical capital and human capital tend to be complements, rather than substitutes, in production; recent evidence for this in the domestic (U.S.) literature is Goldin and Katz (1998) and in the MNE literature is found in Slaughter (2000). We nest a CES production function within the Cobb-Douglas function to

---

[22]Note it is not necessary that plants (firms) require only physical (human) capital to setup plants (firms); what is necessary is that setups of plants (firms) are *relatively* more physical (human) capital intensive, which we conjecture is true empirically. Also, the model is robust to assuming instead that plants (firms) require human (physical) capital for setups. The key is that there are two factors used in setups, and that the two setups have different relative factor intensities, cf., Bergstrand and Egger (2007).

allow for the potential complementarity of physical and human capital in production; χ determines the degree of complementarity or substitutability.

NEs and MNEs differ in fixed costs. Each NE incurs only one firm (or headquarters) 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, 2002) and a plant setup for its home market and for each foreign market it enters endogenously. A horizontal MNE has headquarters at home and plants in two or three markets to serve them; it has no exports. A vertical MNE has headquarters at home and one plant abroad, which can export to any market. Maximizing profits subject to the above technology yields a set of conditional factor demands reported later.

A.3. Homogeneous Goods Producers

We assume 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, $p_{Y1} = w_{U1} = 1$.

A.4. Profit Functions, Pricing Equations, and the Definition of FDI

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

$$\begin{aligned}
\pi_{ni} &= (p_{Xi} - c_{Xi})\sum_{j=1}^{3} x_{ij} - a_{Sni}w_{Si} - a_{Kni}r_i \\
\pi_{h3,i} &= \sum_{j=1}^{3}(p_{Xj} - c_{Xj})x_{jj} - a_{Sh3i}w_{Si} - a_{Kh3i}[3 + \sum_{j\neq i}\gamma_{ij}]r_i \\
\pi_{h2,ij} &= (p_{Xi} - c_{Xi})x_{ii} + (p_{Xj} - c_{Xj})x_{jj} - a_{Sh2i}w_{Si} - a_{Kh2i}[2 + \gamma_{ij}]r_i \\
\pi_{v,ij} &= (p_{Xj} - c_{Xj})\sum_{m=1}^{3} x_{jm} - a_{Svi}w_{Si} - a_{Kvi}[1 + \gamma_{ij}]r_i
\end{aligned} \qquad \text{(8a-8d)}$$

Eq. (8a) 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, respectively, fixed human and physical capital costs for the NE producer. Eq. (8b) is the profit function for each HMNE in country i with three operations. The last two terms in (8b) represent fixed costs of each 3-country HMNE. As with national firms, the HMNE incurs a single fixed cost of home skilled labor to setup a firm. However, each 3-country HMNE 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 foreign direct investment barrier). Consequently, in the context of our model, the flow (and stock) of FDI of country i's representative three-country HMNEs in j (if profitable) would be $a_{Kh3i}r_i\ (1+\gamma_{ij})$; in our model, international capital "mobility" is defined as country i's physical capital being used abroad (say, in j), but the factor rewards are earned in i.[23] Eq. (8c) is the profit function for each HMNE in country i with two operations (one at home and one abroad in j); FDI from i to j is defined analogously, $a_{Kh2i}r_i\ (1+\gamma_{ij})$. Finally, eq. (8d) is the profit function for a vertical MNE with a headquarters in i and a plant in j; FDI

[23]Note that, while physical capital can be "utilized" in different countries, the "ownership" of any country's endowment of such capital is immobile, cf., Jones (1967) and footnote 12. In the typical 2x2x2 model, headquarters use home skilled labor exclusively for setups; home (foreign) plants use home (foreign) skilled labor for setups (cf., 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.

from i to j is analogously $a_{Kvi}r_i\ (1+\gamma_{ij})$.

A key element of our model is that – in each country – the numbers of NEs (type n), three-country HMNEs (type h_3), two-country HMNEs (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:

$$p_{Xi} \leq \frac{c_{Xi}(\varepsilon - 1)}{\varepsilon} \tag{9}$$

Second, free entry and exit ensures:

$$\begin{aligned}
&a_{Sni}w_{Si} + a_{Kni}r_i \geq \frac{c_{Xi}(\varepsilon-1)}{\varepsilon}\sum_{j=1}^{3}x_{ij} \\
&a_{Sh3i}w_{Si} + a_{Kh3i}[3+\sum_{i\neq j}\gamma_{ij}]r_i \geq \sum_{j=1}^{3}\frac{c_{Xj}(\varepsilon-1)}{\varepsilon}x_{jj} \\
&a_{Sh2i}w_{Si} + a_{Kh2i}[2+\gamma_{ij}]r_i \geq \frac{c_{Xi}(\varepsilon-1)}{\varepsilon}x_{ii} + \frac{c_{Xj}(\varepsilon-1)}{\varepsilon}x_{jj} \\
&a_{Svi}w_{Si} + a_{Kvi}[1+\gamma_{ij}]r_i \geq \frac{c_{Xj}(\varepsilon-1)}{\varepsilon}\sum_{m=1}^{3}x_{jm}
\end{aligned} \tag{10a)-(10d}$$

A.5. 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 below. The conditional factor demands for final goods production are given by:

$$\begin{aligned}
K^*_{Xi} &= F_{Xi}\underbrace{\frac{1}{B}\left(\frac{w_{Ui}}{r_i}\frac{\alpha}{1-\alpha}\right)^{1-\alpha}T_{1i}^{\frac{\alpha(\chi-1)-\chi}{\chi}}}_{a_{KXi}} \\
S^*_{Xi} &= F_{Xi}\underbrace{\frac{1}{B}\left(\frac{w_{Ui}}{w_{Si}}\frac{\alpha}{1-\alpha}\right)^{1-\alpha}T_{2i}^{\frac{\alpha(\chi-1)-\chi}{\chi}}}_{a_{SXi}} \\
U^*_{Xi} &= F_{Xi}\underbrace{\frac{1}{B}\left(\frac{r_i}{w_{Ui}}\frac{1-\alpha}{\alpha}\right)^{\alpha}(T_{1i}^{-\chi}+T_{2i}^{-\chi})^{\frac{-\alpha}{\chi}}}_{a_{UXi}}
\end{aligned} \tag{11}$$

where B is a constant and we introduce definitions:

$$T_{1i} = 1 + \left(\frac{r_i}{w_{Si}}\right)^{\frac{\chi}{1-\chi}}; \; T_{2i} = 1 + \left(\frac{w_{Si}}{r_i}\right)^{\frac{\chi}{1-\chi}} \tag{12}$$

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

$$K_i \geq a_{KXi}\left[n_i \sum_{j=1}^{3} x_{ij} + x_{ii}\left(\sum_{j=1}^{3} h_{3,j} + \sum_{j \neq i} h_{2,ji} + \sum_{j \neq i} h_{2,ij}\right) + \sum_{j \neq i} v_{ji}\left(\sum_{j=1}^{3} x_{ij}\right)\right] +$$

$$a_{Kni}n_i + a_{Kmi}\left\{\left[3 + \sum_{j \neq i} \gamma_{ij}\right]h_{3,i} + [2+\gamma_{ij}]h_{2,ij} + [1+\gamma_{ij}]v_{ij}\right\}$$

$$S_i \geq a_{SXi}\left[n_i \sum_{j=1}^{3} x_{ij} + x_{ii}\left(\sum_{j=1}^{3} h_{3,j} + \sum_{j \neq i} h_{2,ji} + \sum_{j \neq i} h_{2,ij}\right) + \sum_{j \neq i} v_{ji}\left(\sum_{j=1}^{3} x_{ij}\right)\right] +$$

$$a_{Sni}n_i + a_{Smi}(h_{3,i} + \sum_{j \neq i}\left(h_{2,ij} + v_{ij}\right))$$

$$U_i \geq a_{UXi}\left[n_i \sum_{j=1}^{3} x_{ij} + x_{ii}\left(\sum_{j=1}^{3} h_{3,j} + \sum_{j \neq i} h_{2,ji} + \sum_{j \neq i} h_{2,ij}\right) + \sum_{j \neq i} v_{ji}\left(\sum_{j=1}^{3} x_{ij}\right)\right] + a_{UYi}\sum_{j=1}^{3} t_{Yij}Y_{ij} \tag{13}$$

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

$$(n_i + v_{ji} + v_{mi})p_{Xi}(x_{ij} + x_{ik}) + p_{Yj}Y_{ij} + p_{Ym}Y_{im}$$

$$+\frac{1}{1-\varepsilon}([h_{2,ij} + h_{3,i}]p_{Xj}x_{jj} + [h_{2,im} + h_{3,i}]p_{Xm}x_{mm})$$

$$+\frac{1}{1-\varepsilon}(v_{ij}p_{Xj}[x_{jj} + x_{ji} + x_{jm}] + v_{im}p_{Xm}[x_{mm} + x_{mi} + x_{mj}])$$

$$=$$

$$(n_j + v_{ij} + v_{mj})p_{Xj}x_{ji} + (n_m + v_{im} + v_{jm})p_{Xm}x_{mi} + p_{Yi}(Y_{ji} + Y_{mi})$$

$$+\frac{1}{1-\varepsilon}(h_{2,ji} + h_{3,j} + h_{2,mi} + h_{3,m})p_{Xi}x_{ii}$$

$$+\frac{1}{1-\varepsilon}(v_{ji} + v_{mi})p_{Xi}(x_{ii} + x_{ij} + x_{im}) \tag{14}$$

The first line in equation (14) represents the exports of 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 m (m denoting the *ROW* for country i). The fourth line represents country i's imports of goods from j and m. The fifth and sixth lines represent i's repatriation of income on capital of countries' j and m invested in country i in horizontal and vertical affiliates, respectively.

Appendix B: Calibration of Model
[NOT INTENDED FOR PUBLICATION]

The complexity of the model (including the complementary-slackness conditions) introduces a high degree of nonlinearity, and it cannot be solved analytically. Consequently, as in Markusen (2002) we provide numerical solutions to the model. With three countries, we have several potential types of asymmetries, e.g., large vs. small GDPs, developed vs. developing economies. We focus initially on bilateral flows between three identical economies (in absolute and relative factor endowments). We then introduce absolute and relative factor endowment asymmetries. We use *GAMS* for our numerical analysis. The calibration of the model is very similar to that in Bergstrand and Egger (2007).

B.1. Values of (Exogenous) Factor Endowment, Trade Cost, and Investment Cost Variables

We assume a world endowment of capital (*K*) of 500 units, skilled labor (*S*) of 200 units, and unskilled labor (*U*) of 2000 units. Initially, countries *i* and *j* together have half of the world's endowments of each factor, and *i*'s and *j*'s factor endowments are identical.

"Trade costs" include both the costs of shipping and distributing goods, as well as trade policies. Initially, we set the former costs for good *X* and good *Y* at (*ad valorem* equivalents of) 30 percent and 45 percent, respectively. This reflects recent estimates that homogeneous goods' transport costs are higher than those of differentiated goods, cf., Bergstrand and Egger (2006). Both values exceed estimated (c.i.f.-f.o.b.)/f.o.b. factors in that paper of 15 and 20 percent, respectively. However, values used are in the range of levels discussed in Anderson and van Wincoop (2004) on trade costs. For simplicity, we set tariff rates initially at *ad valorem* equivalents of 2 percent.

In reality, of course, informational costs and policy barriers to FDI exist between countries. We assumed initially a "tax-rate" equivalent (for γ) of 60 percent for FDI.

B.2. Utility and Technology Parameter Values

Consider first the utility function (see Appendix A equation (1) for details). The only two parameters are the Cobb-Douglas share of income spent on differentiated products from various producers (η) and the CES parameter (ε) influencing the elasticity of substitution between differentiated products ($\sigma \equiv 1-\varepsilon$). Initially, we use 0.71 for the value of η, based upon an estimated share of manufactures trade in overall world trade averaged between 1990 and 2000 using 5-digit SITC data from the UNs' COMTRADE data set, which is a plausible estimate. The initial value of ε is set at -5, implying an elasticity of substitution of 6 among differentiated final goods, consistent with a wide range of recent empirical studies estimating the elasticity between 2 and 10, cf., Feenstra (1994) and Head and Ries (2001).

Consider next the production function for differentiated goods (see Appendix A equation (7) for details). Labor's share of differentiated goods gross output is assumed to be 0.8; the Cobb-Douglas formulation implies the elasticity of substitution between capital and labor is unity. Griliches (1969) proposed – in a three-factor world with unskilled labor, skilled labor, and physical capital – that skills were more complementary with physical capital than with unskilled labor in production. 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 human and physical capital are relatively complementary in production, cf., Goldin and Katz (1998). In 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 a technical rate (elasticity) of substitution of 0.8 [=1/(1-χ)] and complementarity between physical and human capital.

As in the 2x2x2 KC model in CMM (2001), a firm (or headquarters) setup uses only skilled labor. For national final goods producers, we assume a headquarters setup requires one unit of skilled labor per unit of output ($a_{Sn,1}=a_{Sn,2}=a_{Sn,3}=1$). As in the knowledge-capital model, we assume "jointness" for MNEs; 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 horizontal or vertical MNE relative to a domestic firm ranges from 1 to 2 (for a 2-country model). We assume initially a headquarters cost for MNEs of 1.01 ($a_{Sh,1}$=$a_{Sh,2}$=$a_{Sh,3}$=$a_{Sv,1}$=$a_{Sv,2}$=$a_{Sv,3}$=1.01) ; hence, 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 two units of home physical capital (a_K=2); however, MNEs setting up plants abroad face additional fixed investment costs (γ), for which we assumed a value of 0.60 (60 percent).

In the results that follow, theoretical relationships are qualitatively similar for a wide range of alternative values of the parameters (results of which are available on request).

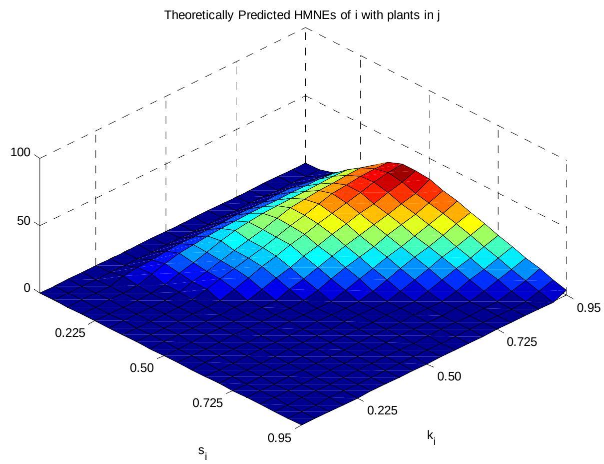


Figure A1a: 30[th] Percentile of u_i

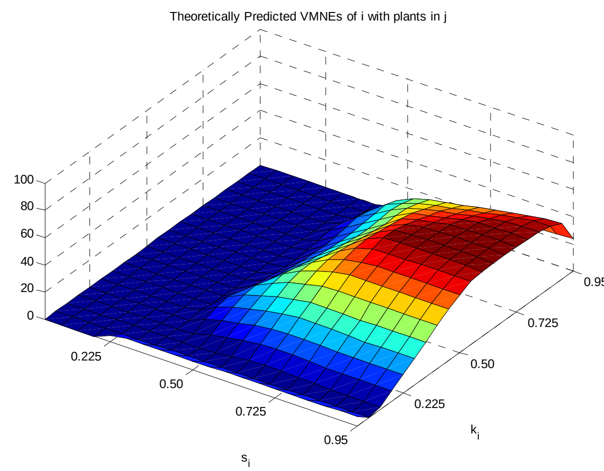


Figure A1b: 30[th] Percentile of u_i

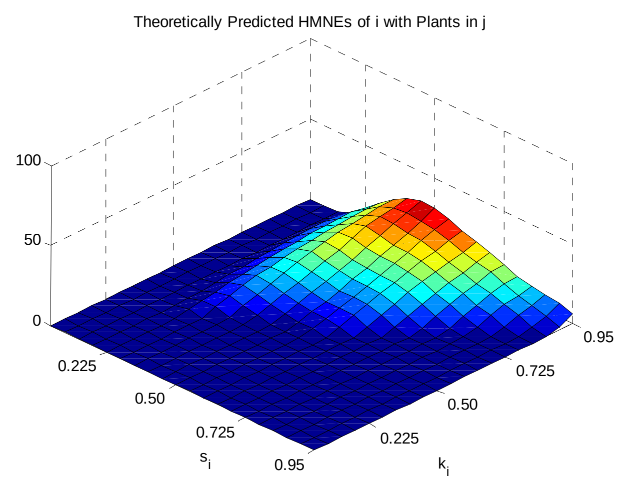


Figure A1c: Mean of u_i

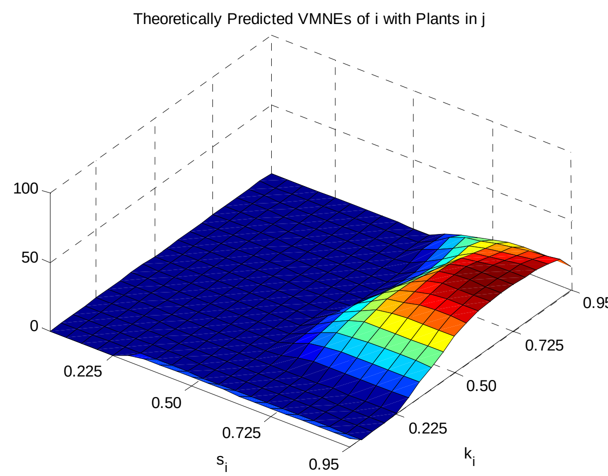


Figure A1d: Mean of u_i

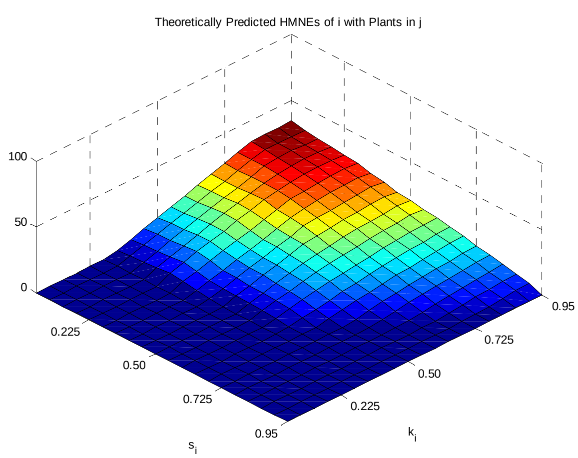


Figure A1e: 70[th] Percentile of u_i

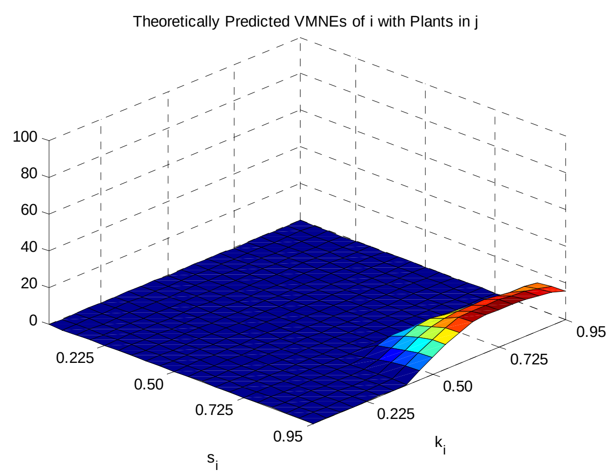


Figure A1f: 70[th] Percentile of u_i