INTERNATIONAL TRANSMISSION WITH HETEROGENEOUS SECTORS*

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Abstract

In this paper, we (1) document new facts about the behavior of capital and labor-intensive goods over the business cycle; (2) illustrate a mechanism that generates international investment comovement through shifting compositional changes of production and trade across sectors. Quantitative predictions of our model can match aggregate and sectoral statistics and generate empirically plausible sectoral compositional effects. Essential segments of the transmission process receive empirical support.

Keywords: International Business Cycles, International Comovement, Relative Prices, Factor-proportions trade

JEL Classification: F41, F44

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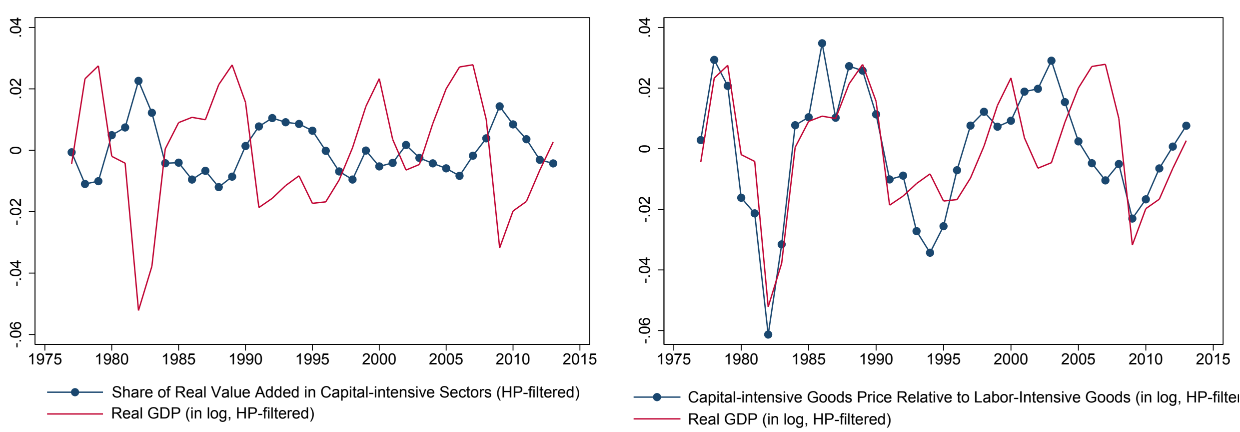
1 Introduction

Studies of international business cycle theory anchored in large open-economy stochastic growth models assume homogeneous factor intensities across different goods. The reality is that some sectors use capital more intensively in their production process, and others use labor more intensively. Factor intensity differences are large across sectors.

A close inspection of the data points to distinctive patterns that set apart labor-intensive from capital-intensive sectors. There are systematic changes in the *composition of production* of capital and labor-intensive sectors over the business cycle—manifested by a strongly countercyclical share of production in capital-intensive sectors (Figure I(a)). Between 1977 and 2013, the correlation of the cyclical components of capital-intensive sectors' production share and real GDP in the U.S. is -0.82, corroborated by a high correlation of -0.58 for their employment share.

Equally striking is the behavior of the relative price of capital-intensive goods to labor-intensive goods over business cycles. As shown in Figure I(b), this relative price is strongly proyclical and tracks business cycles closely (correlation=0.70). Booms are associated with a rise in the relative price of capital intensive goods, while recessions are accompanied by a decline.[1]

Figure I: Sectoral Compositional Changes and the Business Cycle

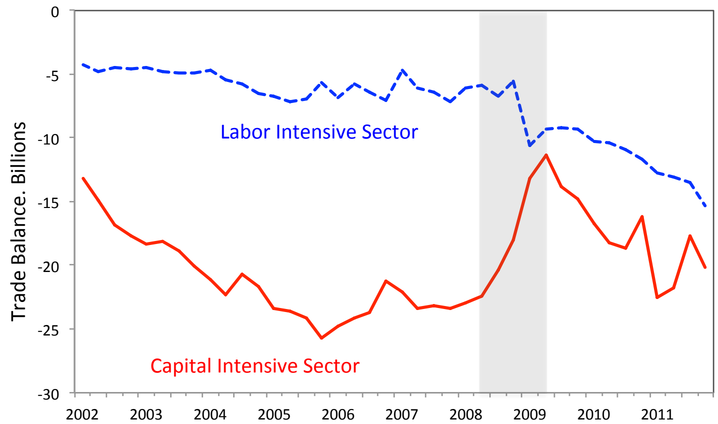


(a) Production Share (b) Relative Price

Notes: The cyclical components of two series—(a) share of real value-added in the capital-intensive sectors, and (b) the relative price of the capital-intensive sectors compared to the labor-intensive sectors—in relationship with the business cycle are shown here. Data source: U.S. BEA Industry Economic Accounts and National Account, 1977-2013. All private sectors at the most disaggregated level (NAICS 2-4 digit) are divided into two larger sectors—labor-intensive sector and capital-intensive sector–according to their labor share in value-added. Additive real value-added (at constant prices) in each disaggregated sector are then aggregated into these two sectors. Sectoral price is calculated as nominal value-added over (constant price) real value-added. See Appendix A for more details.

[1]These patterns are highly robust across many OECD industrial economies. The average correlation between real value added share of capital intensive sectors and business cycles is -0.63 and between the employment share and business cycles is -0.53, respectively, for OECD economies in our sample. Appendix A provides detailed explanations on the definition of capital- and labor-intensive sectors.

Figure II: U.S. Manufacturing Trade Balance with EU15 in Capital- and Labor-intensive Sectors



Notes: Data source: U.S. International Trade Commission. Manufacturing sectors at the most disaggregated level (NAICS 6-digit) are aggregated into two larger groups—capital-intensive and labor-intensive sectors—according to their labor shares in industry value-added (calculated based on the NBER manufacturing industry data). Quarterly export and import data are seasonally adjusted using Census X-12 method. See Appendix A for more details.

Another pattern is that the *composition of trade* of capital and labor-intensive goods can also vary over the business cycle. The recent recession of 2008-2009 is a case in point. Along with the collapse of trade over this period that has aroused significant interest was a notable change in the composition of trade—with the net exports of capital-intensive goods from the U.S. to EU15 economies improving by 11 billion dollars, while that of labor-intensive sectors deteriorating by 4 billion dollars (Figure II). This was accompanied by a significant drop in the price of capital-intensive goods relative to labor-intensive goods, about 10% over the period of August 2008–December 2009.

Motivated by these patterns on the behavior of capital and labor-intensive goods over the business cycle, this paper endeavors to achieve two goals. The first goal is to investigate the business cycle properties of a multi-sector stochastic growth model in which compositional changes across different sectors (characterized by different factor intensities) within a country are in line with the above empirical patterns. A new transmission mechanism of real business cycle shocks across countries arises—through the relative price of capital to labor-intensive goods. The mechanism presents a channel through which shocks are *positively* transmitted across countries. By positive we mean that investment and output tend to move together across countries in response to *country-specific* productivity shocks. This leans against the standard model in which investment and output rise in the country with the positive productivity shock while falling abroad—as investment tends to flow towards the more productive economy—a cross-country "resource allocation effect". The second goal is to assess the quantitative properties of this multi-sector model, examining and empirically assessing both aggregate and new sectoral statistics. The strategy adopted is to estimate the model from the behavior of sectoral production and aggregate variables in the U.S. data, and then to evaluate the model in terms of its ability to deliver international comovement in investment and output across countires.

The mechanism we propose in this paper relies on the *interaction* between factor-trade dynamics and macroeconomic forces. A country (Home) hit by a country-specific positive shock expands disproportionately its labor-intensive sector—consistent with the above empirical observation—causing the world supply of labor-intensive goods to increase and thereby raising the relative price of capital-intensive goods. The Foreign economy, facing a higher relative price of capital-intensive goods, shifts resources to that sector. The change in the Foreign *composition* of production and exports towards capital-intensive sectors leads to a rise in their aggregate demand for investment, inducing Home to allocate investment resources not only to the domestic economy but also to the Foreign economy which has become more capital-intensive in production—a "composition effect". The net import of investment resources in Foreign combined with greater production of capital-intensive goods leads to a rise in Foreign GDP. This trade-induced investment flow, under conditions met by the data, is shown to quantitatively dominate the standard "resource allocation effect" across countries and generate positive international comovement.

The framework is a two-country stochastic growth model, in which sectors differ by factor intensity. All intermediate goods are produced by each country (no ex-ante specialization), and are divided into a set of labor-intensive and a set of capital-intensive goods. Trade and asymmetries across countries are due to differences in productivity at the business cycle frequency. It is important to note that the main endogenous force hinges on the fact that the foreign economy responds to a positive Home productivity shock by producing more *capital-intensive* goods—which require more investment—rather than just any good. In the absence of factor intensity differences across goods, we show that international investment correlations are still negative—driven by the strong neoclassical force that tends to send investment towards countries that are more productive. This is what marks our model from the two-sector Armington trade model as commonly adopted in the IRBC literature.

Indeed, the terms of trade fluctuations in standard models can generate positive output comovements, but the investment dynamics are often dominated by the strong cross-country resource allocation effect.[2] As shown by Heathcote and Perri (2000), positive investment comovement does not arise in a two-good Armington model with complete markets or with a bond economy, but only

[2]For example, Karabarbounis (2013) incorporates a "labor wedge"—the gap between the marginal product of labor and the marginal rate of substitution of leisure for market consumption—into the workhorse IRBC model a la Backus Kehoe and Kydland (1992), to account for several open-economy puzzles. However, the negative correlation of investment across countries still prevails.

emerges in the case of complete financial autarky, when the resource-allocation effect is shut off and foreign terms of trade appreciates by a large magnitude to induce foreign investment to increase.[3] In an endogenous incomplete markets model where international loans are imperfectly enforceable, Kehoe and Perri (2002) shows that the need to satisfy enforcement constraints significantly reduces the amount of investment that is accrued to the country hit by a positive and persistent shock, achieving foreign and domestic investment comovements. In contrast to Kehoe and Perri (2002), the endogenous mechanism we propose in this paper is induced by factor-proportions-based trade and is independent of asset market structure.

Our mechanism, however, does not offer additional insight into the consumption/output anomaly or countercyclical trade balance puzzles beyond what have already been established by the models with limited risk sharing (Baxter and Crucini (1995), Kollman (1996), Heathcote and Perri (2000), Kehoe and Perri (2002)). But where exogenous-incomplete-markets models are in need of an endogenous mechanism that draws international investment together, this alternative explanation can potentially fill the gap. Our focus is also slightly different—shifting the attention to the behavior of sectoral statistics and a new relative price over the business cycle. The relevant price for the mechanism is the relative price of capital to labor-intensive goods. We show that it displays robust patterns across the majority of OECD countries: it is about as volatile as GDP in the U.S. Over the period of 1977-2013, the standard deviation of the (log) relative price of capital-intensive goods to labor-intensive goods in the U.S. is 2.09, against an aggregate GDP volatility of 1.92. Its cyclicality is also distinct and robust: the contemporaneous correlation of the cyclical component of the relative price of capital- to labor-intensive goods with that of GDP is 0.70. Similar patterns hold for other OECD countries.[4]

We then assess each segment of the transmission channel in the data. When dissecting sectors by factor intensity, we find that based on U.S. data, (1) booms are associated with a larger expansion of its labor-intensive sector relative to its capital-intensive sectors—both in inputs and outputs, and vice versa. This delivers the "domestic composition effect" that is necessary to instigate our international transmission channel; (2) the relative prices of sectors that use labor input more intensively tend to be more countercyclical; (3) net exports of capital-intensive sectors to OECD economies tend to be more countercyclical than that of their labor-intensive sectors; and based on OECD cross-country evidence, (4) domestic booms (recessions) are associated with a greater

[3] Corsetti, Dedola and Leduc (2008) study a two-country incomplete markets model with Armington type of trade with a focus on the Backus-Smith puzzle. The positive comovement in input and output across countries in their paper obtains when there is a positive correlation of sectoral shocks across countries. An appreciation of the terms of trade helps strengthen the comovement, as it induces large negative wealth effect abroad and raise labor effort there.

[4] The peak cross-correlation between (normalized) capital-intensive prices and the business cycle for Canada is 0.25, Denmark 0.44, Finland 0.45, Germany 0.69, Hungary 0.56, Italy 0.49, Netherlands 0.65, and UK 0.27.

expansion (contractions) in labor-intensive sectors, but a foreign boom (recession) is associated with a greater domestic expansion (contraction) in capital-intensive sectors; (5) booms (recessions) in either domestic or foreign economies are associated with a fall (rise) in the relative price of labor-intensive goods—consistent with the 'international propagation mechanism' that our theory highlights.

A few points merit mention. Distinguishing sectors based on their factor intensity of production is not equivalent to categorizing sectors based on their tradability (tradables vs nontradables) or durability (durables vs non-durables). Contrary to customary beliefs, durable goods or capital goods are not distinctively capital-intensive, nor are nontradable goods distinctively labor-intensive.[5] The IRBC literature in the past has focused primarily on the dichotomous grouping of sectors along these dimensions of tradability or durability, and applications of such, in Stockman and Tesar (1995) and Engel and Wang (2011), among others, have been wide-ranging and implications far-reaching. New patterns in the data point to an alternative way of slicing sectors that may help understand other empirical peculiarities.

Second, the evidence we present may challenge some preconceived notion that factor-proportions trade cannot occur over the business cycle—or that it cannot occur among industrialized economies. In the first instance, our theory does not prescribe factor-content trade in the medium/long run. Compositional changes in production and trade in our economy are driven by temporary productivity shocks rather than by factor endowment differences, which are absent for ex-ante symmetric countries. All that is required and what is paramount is that the factor intensity of trade is *unsynchronized* across industrialized countries—over the business cycle. We find in the data sufficiently volatile trade in capital and labor-intensive goods to generate a positive transmission mechanism in the model.

One may also be skeptical of any sectoral "reallocations" in the short run. But it is important to recognize that compositional changes stem primarily from flow of investment, which, given its mobility and versatility in being directed to profitable projects, is quite reasonable.[6] [The employment reallocation that is required by the model is quantitatively small, and is consistent with observations from the data.] [SHALL WE REMOVE THIS SENTENCE, SINCE OUR

[5] Studying sectoral level data shows that there is no clear relationship between the durability or tradability of a good with the factor intensity of production. Durable goods can be relatively labor-intensive—for instance, computer and electronic products—or capital-intensive, for example, electrical equipment and appliances. Similarly, nontradable goods could also be capital-intensive–for example, utilities, legal or financial services. Also, the conventional separation of capital goods and consumption goods are based on their end-use, not on intensity of input factors. Some capital goods are actually labor-intensive in production—for instance, computer and electronic products.

[6] Capital does not flow across sectors—it is aggregate investment distributed across country-sectors that augments or reduces capital stock in each particular sector. The model is in this sense intrinsically different from a Heckscher-Ohlin model, which allows for instantaneous reallocation of capital stock across sectors. These specifications are closer to a specific-factors model with capital accumulation.

EMPLOYMENT MOMENTS DO NOT MATCH THE DATA?] All in all, the size of compositional changes and magnitudes of factor-proportions trade as predicted by the quantitative model are in line with the data, suggesting that no unrealistic degrees of compositional changes and trade over the business cycle is needed for our channel to operate.

Lastly, a rudimentary motive for trade is assumed in this paper. It is by keeping the structure of trade simple that its interactions with macroeconomic forces are made most transparent. We are interested in how one realistic dimension of the data—factor intensity differences across sectors—impacts the international business cycle, although more complex structures of trade can be easily embedded to account for other features of the data.

By endogenizing the trade patterns in an international business cycle context, this paper also attempts to join forces that bridge the gap between IRBC theory and international trade theory. Burstein, Kurz and Tesar (2008) examine the role of the vertically integrated production-sharing trade on international business cycle synchronization. Ghironi and Melitz (2005) incorporate Melitz's (2003) model of trade with monopolistic competition and heterogeneous firms in a business cycle context, and focus on explaining endogenously persistent deviations from PPP. Cuñat and Maffezzoli (2004) study the business cycle properties of a two-country model with Hecksher-Ohin trade where countries are characterized by asymmetric factor endowments. With a different transmission mechanism from ours, they focus on explaining why the correlation between the terms of trade and income can be positive or negative for different countries.[7] In a long-run two country, two-sector overlapping generations model, Jin (2012) derives theoretical results on the determinants of international capital flows driven by factor proportions trade to address the question of why capital can flow from "poor" to "rich" countries. The absence of empirical evidence on the behavior of capital/labor-intensive sectors over the business cycle in these papers and past literature is a gap in which we intend to fill with this current work.

The paper is organized as follows. Section 2 extends the standard large open-economy framework to incorporate multiple sectors with heterogeneous factor intensities. Section 3 provides the intuition of the mechanism. Section 4 discusses calibration, estimation of the model and examines the dynamic and quantitative properties of the model. Section 5 investigates the key implications

[7]More specifically, Cuñat and Maffezzoli (2004) differs from our work along three dimensions—the transmission mechanism, the empirical investigation we undertake, and the key questions we pursue. Their use of TFP shocks in combination with asymmetric endowments across countries generates different initial trade patterns, and does not produce the "domestic composition effect" we need to instigate our propagation mechanism. In the absence of these effects, positive comovement in inputs and outputs does not emerge in their setting. Their main experiment examines an increase in productivity in the *capital-abundant* country. Since this increase in productivity raises the country's capital and labor (in efficiency units) by the same proportions, the world's capital-labor ratio in efficiency units also rises. In contrast, an increase in labor force/productivity in this economy *reduces* the worlds' capital-labor ratio upon impact. Different production and trade patterns ensue, and the resource shifting effect remains the dominant force in their model.

of the model using sectoral data at the most disaggregated level available. Section 6 concludes.

2 Model

2.1 Preferences and Technologies

Consider a two-country world, Home and Foreign, each populated by a large number of identical, infinitely lived consumers. The countries produce and trade the same type of intermediate goods $i = 1, ..., m$, conveniently indexed by their labor intensity, $1 - \alpha_i > 1 - \alpha_j$ for $i > j$.[8] Preferences and technologies are assumed to have the same structure across countries.

In each period t, the world economy experiences one of finitely many events s_t. Denote $s^t = (s_0, ...s_t)$ the history of events up through and including period t. The probability, as of period 0, of any particular history s^t is $\pi(s^t)$. Consumers in country j have the standard preferences

$$\sum_{t=0}^{\infty} \sum_{s^t} \pi(s^t) \beta^t \exp(\lambda_t) U(c^j(s^t), l^j(s^t)), \tag{1}$$

where $c^j(s^t)$ denotes consumption per capita and $l^j(s^t)$ denotes labor at time t, history s^t in country j. The β is a subjective discount factor and the term λ_t represents an intertemporal preference shock. We consider a general form of preferences, proposed by Jaimovich and Rebelo (2009), to allow for a flexible degree of income effect: $U(c, l) = [(c_t - \kappa l_t^{\psi} x_t)^{1-\sigma} - 1]/(1 - \sigma)$, where $x_t = c_t^{\nu} x_{t-1}^{1-\nu}$. This preference specification nests two special cases of widely used utility function in the real business cycle literature: the preference proposed by Greenwood, Hercowitz and Huffman (1988) (GHH) when $\nu = 0$, and the one discussed in King, Plosser and Rebelo (1988) (KPR) when $\nu = 1$.

The production technology employs capital and labor to produce an intermediate good i in country j:

$$Y_i^j(s^t) = A_i^j(s^t)(K_i^j(s^{t-1}))^{\alpha_i}(l_i^j(s^t))^{1-\alpha_i}, \tag{2}$$

where $0 < \alpha_i < 1$, $Y_i^j(s^t)$ is the gross production of intermediate good i in j at s^t, $K_i^j(s^{t-1})$ is the capital stock in sector i of country j. Production of intermediate goods is subject to a country-sector-specific random shock $A_i^j(s^t)$, which follows an exogenous stochastic process.

Intermediate goods are combined with an elasticity of substitution θ to form a unit of final good, which is used for two purposes: consumption, $c^j(s^t)$, and investment, $x^j(s^t)$. The consumption good

[8] We focus on the case in which countries do not completely specialize in production.

takes the form of

$$c^j(s^t) = \left[\sum_{i=1}^{m} \gamma_i^{\frac{1}{\theta}} \left(c_i^j(s^t) \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}, \tag{3}$$

where $c_i^j(s^t)$ is the consumption demand for good i in j, and the share parameters satisfy $\sum_i \gamma_i = 1$, and $\theta > 0$. The investment good in sector i takes the same form as the consumption good:

$$x_i^j(s^t) = \left[\sum_{k=1}^{m} \gamma_k^{\frac{1}{\theta}} \left(z_{ki,t}^j(s^t) \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}, \tag{4}$$

where $z_{ki,t}^j(s^t)$ denotes the amount of good k used for investment in the i'th sector of country j. Aggregate investment in country j at s^t is $x^j(s^t) = \sum_i x_i^j(s^t)$.

The evolution of capital stock in sector i of country j is subject to the quadratic adjustment cost, and follows:

$$K_i^j(s^t) = (1-\delta)K_i^j(s^{t-1}) + x_i^j(s^t) - \frac{b_i}{2} K_i^j(s^{t-1}) \left(\frac{K_i^j(s^t)}{K_i^j(s^{t-1})} - 1 \right)^2, \tag{5}$$

where δ denotes the depreciation rate, and b_i denotes the adjustment cost parameter.[9]

Intermediate goods are traded across countries, with $p_i(s^t)$ denoting the relative price of good i in terms of the final good. And normalize the price of the final good $P(s^t)$ to 1 so that

$$P(s^t) = \left[\sum_{i=1}^{m} \gamma_i p_i(s^t)^{1-\theta} \right]^{\frac{1}{1-\theta}} \equiv 1. \tag{6}$$

The consumption and investment demands are, respectively:

$$c_i^j(s^t) = \gamma_i \left(p_i(s^t) \right)^{-\theta} c^j(s^t), \tag{7}$$

$$z_{ki}^j(s^t) = \gamma_k \left(p_k(s^t) \right)^{-\theta} x_i^j(s^t). \tag{8}$$

2.2 Budget Constraints and Asset Markets

Complete Asset markets The complete markets economy assumes that a full set of state contingent securities are traded. Let $B^j(s^t, s_{t+1})$ denote j's holdings of a state-contingent bond purchased in period t and state s^t that pays 1 unit of consumption contingent on s_{t+1} at $t+1$.

[9]This adjustment cost, in addition to uninsured risks, helps to break the factor price equalization across countries in equilibrium.

Let $Q(s^{t+1}|s^t)$ denote the price of this bond in period t and state s^t. Agents in the two economies maximize their expected lifetime utilities, given in Eq. (1), subject to the following constraints:

$$c^j(s^t) + x^j(s^t) + \sum_{s_{t+1}} Q(s^{t+1}|s^t) B^j(s^{t+1}) = B^j(s^t) + w^j(s^t) l^j(s^t) + r^j(s^t) K^j(s^{t-1}), \tag{9}$$

where $w^j(s^t)$ and $r^j(s^t)$ are the wage and the net return on capital in country j. The international bond market-clearing requires that $\sum_j B^j(s^t) = 0$ for all s^t.

Bond Economy In the bond economy, the menu of assets that are traded internationally is exogenously limited to a single non-state contingent bond. The remaining primitives are the same as in the economy described above. The budget constraints associated with the consumer's problem in this economy are

$$c^j(s^t) + x^j(s^t) + q(s^t) b^j(s^t) = b^j(s^{t-1}) + w^j(s^t) l^j(s^t) + r^j(s^t) K^j(s^{t-1}) - \phi \frac{(b^j)^2}{2}, \tag{10}$$

where $q^j(s^t)$ is the period t price of the uncontingent bond that pays one unit of the consumption good in period $t+1$ regardless of the state of the world, $b^j(s^t)$ denotes the amount of bonds purchased at t by a consumer in j, and ϕ is the parameter governing the international bond adjustment costs. The international bond market-clearing requires that $\sum_j b^j(s^t) = 0$ for all s^t.

2.3 Market Clearing Conditions

Intermediate goods markets clear when global demand of each sectoral good i equals its global supply:

$$\sum_{j=H,F} c_i^j(s_t) + \sum_{j=H,F} \sum_{k=1}^{m} z_{i,k}^j(s^t) = \sum_{j=H,F} Y_i^j(s^t) \tag{11}$$

which, combined with consumption and investment demand in (7) and (8) yields the relative price of any two intermediate goods i and k:

$$\frac{p_i(s^t)}{p_k(s^t)} = \left(\frac{\gamma_i}{\gamma_k} \frac{\sum_j Y_k^j(s^t)}{\sum_j Y_i^j(s^t)} \right)^{\frac{1}{\theta}}. \tag{12}$$

This shows that a greater world supply of good k relative to good i lowers its relative price. In the two-sector example, a greater supply of labor-intensive goods will increase the international relative price of capital-intensive goods. In the face of a high relative price of capital-intensive goods, the Foreign economy will tend to shift resources towards the capital-intensive sector. This is analogous to the well-known result in the specific-factors model of trade. Since analytical solutions are not available, we illustrate these patterns in our impulse responses in Figure III in Section 3.

Labor market clearing requires that in each state of the world,

$$\sum_{i=1}^{m} l_i^j(s^t) = l^j(s^t), \tag{13}$$

where $l^j(s^t)$ is total domestic labor supply at s^t.

2.4 Shock Processes

The country-specific exogenous demand shock follows an AR(1) process:

$$\lambda_t^j = \rho_\lambda \lambda_{t-1}^j + \varepsilon_{\lambda,t}^j, \quad j = H, F \tag{14}$$

where $\varepsilon_{\lambda,t}^j$ is an *i.i.d.* zero-mean normal process with standard deviation given by σ_λ and uncorrelated cross-country: $\text{corr}(\varepsilon_{\lambda,t}^H, \varepsilon_{\lambda,t}^F) = 0$.

For comparability with the past literature, stochastic shocks to sectoral productivity are taken to be country-specific, as in the majority of international business cycle models—Backus et al. (1992), Baxter and Crucini (1995), Kollman (1996), Kehoe and Perri (2002) notwithstanding. Sectors within a country, however, differ in terms of its elasticity (or loading parameter) to the aggregate shocks, z_t^j: $A_{i,t}^j = \exp(\eta_i z_t^j)$. As in the previous literature technology shocks in the two countries $\boldsymbol{z}_t = \{z_t^H, z_t^F\}$ follow a vector autoregressive (VAR) process of the form:

$$\begin{pmatrix} z_t^H \\ z_t^F \end{pmatrix} = \begin{pmatrix} \rho_z & 0 \\ 0 & \rho_z \end{pmatrix} \begin{pmatrix} z_{t-1}^H \\ z_{t-1}^F \end{pmatrix} + \begin{pmatrix} \varepsilon_{z,t}^H \\ \varepsilon_{z,t}^F \end{pmatrix}, \tag{15}$$

where innovations $\varepsilon_t = (\varepsilon_t^H, \varepsilon_t^F)$ are multivariate normal *i.i.d* random variables with the same standard deviation given by σ_z, and contemporaneous correlation given by $\text{corr}(\varepsilon^H, \varepsilon^F) \geq 0$. This specification of technology processes is equivalent to assuming $\log(A_{i,t}^j) = \rho_z \log(A_{i,t-1}^j) + \eta_i \varepsilon_t^j$.

3 The International Transmission Mechanism

We first present a set of impulse responses of domestic and foreign variables to a domestic productivity shock to help develop intuition for the key mechanism at hand. To avoid confounding factors, we examine first the simplest case possible—one with complete asset markets, fixed aggregate labor ($l_t = \bar{l}$ and $\nu = 1$). We focus on the international transmission of technology shocks (as in the literature). And in order to add no other impetus for positive comovement, we first assume that there is zero correlation in the innovations across countries: $\text{corr}(\varepsilon^H, \varepsilon^F) = 0$. The other relevant structural parameters are set at their standard level: β is set to 0.95 (at annual frequency), the risk aversion parameter σ is set to 2 and the depreciation rate δ to 0.1. As will be explained in detail in Section 4.1, we select $\alpha_k = 0.59$, $\alpha_l = 0.16$, $\gamma_l = 0.56$, $\eta_l = 1.673$ and $\eta_k = 1$. The adjustment cost parameter is chosen such that investment volatility relative to output volatility matches the data.

The dynamics of the technology shock is displayed in the lower right panel of Figure III, which shows that it increases by about 1% and then slowly decreases back to its mean. The productivity of the Foreign country stays the same with the assumption of no spillovers (i.e. the coefficient of z^H_{t-1} is zero). On impact, an increase in the aggregate productivity in Home hits disproportionately the labor-intensive sector ($\eta_l/\eta_k = 1.67$), causing the share of its employment and production in aggregate employment and production to rise, and conversely, the share of employment and production of the capital-intensive sector to fall (panels 1 and 3). The absolute levels of output and employment (omitted for convenience) rise however, for both sectors. The increase in the world supply of labor-intensive goods drives down its relative price, and raises the relative price of the capital-intensive good (panel 5). In response to the increase in the relative price of the capital-intensive good, Foreign shifts resources towards the capital-intensive sector. On net, Home becomes a net exporter of the labor-intensive intermediate good and Foreign a net exporter of the capital-intensive intermediate good. Thus, an aggregate technology shock in one country induces compositional changes both domestically and internationally.

These compositional changes impact the aggregate economy and bring about a sharp contrast to the behavior of a one-sector model (Figure IV). As Foreign expands its capital-intensive industry, its demand for investment rises on impact, by about 0.2%. In contrast, in the one-sector model, Foreign investment *falls* sharply, by about 0.8%, as it flows across-borders towards the more productive economy—Home. Home's investment rises in both cases, but by less in the two-sector case (3% in the two-sector model compared to the 4% in the one-sector model) as investment flows are now shared with Foreign.

A net inflow of investment from Home, combined with domestic resources shifted towards the capital-intensive sector in Foreign substantially increases the output of these goods in Foreign. Foreign's GDP also rises, in stark contrast to a fall in the one-sector case. The main difference, thus, between the one-sector and two-sector case, is that investment and output tend to rise in both economies in the latter case whereas they tend to move in opposite directions in the former.

Essentially two forces are at work in determining how resources are allocated across countries in the two-sector economy. First is the standard "resource shifting effect", whereby inputs are shifted

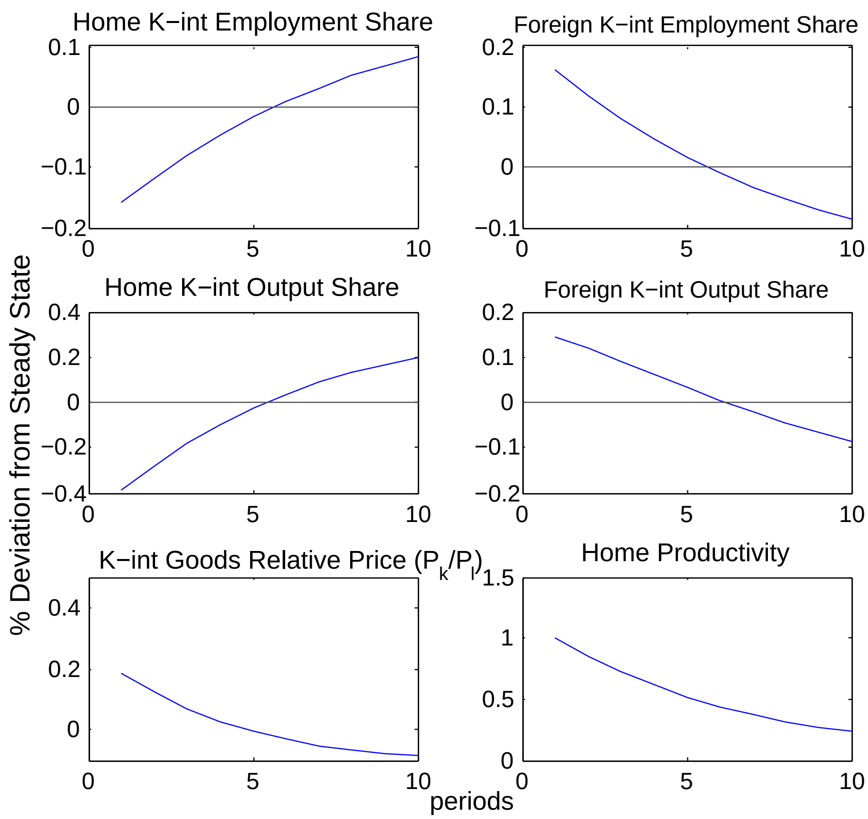


Figure III: Impulse Responses to a Home Productivity Shock (two-sector model)—Sectoral Variables: Complete Markets and Fixed Labor Case.

towards the more productive economy (investment flows towards Home), making both inputs and outputs move in opposite directions across countries. The second force is induced by changes in the composition of production, causing investment to flow towards the country that become more capital-intensive in production structure—in this case, Foreign. If the latter force dominates the resource shifting effect, investment resources flow towards Foreign on net, and aggregate investment rises in both countries.

4 A Quantitative Assessment

Table II reports the quantitative properties of the two-sector model with endogenous labor. The two-good bond model is taken to be the benchmark model. The main result is that the two-sector model can obtain positive international investment comovement, and in turn, output comovement. Moreoever, sectoral statistics match fairly well the data.

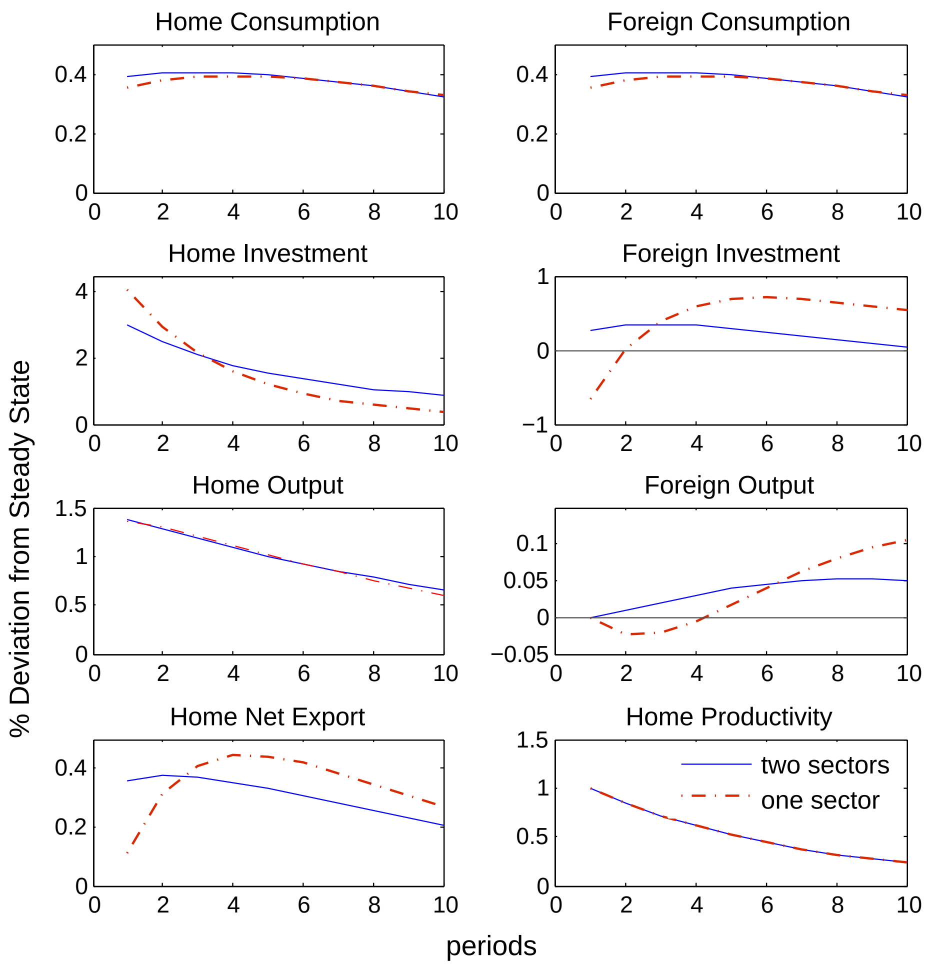


Figure IV: Impulse Responses to a Home Productivity Shock—Economy-wide Variables: Complete Markets and Fixed Labor Case.

4.1 Model Estimation

The model is estimated with annual data as sectoral statistics are only available at a yearly frequency. As in Section 3, the discount rate β is set to 0.95, implying an annual steady-state real interest rate of 5%. The risk aversion parameter σ is set at 2 and the depreciation rate at 0.1. The parameter ψ is set to 2.44, which corresponds to a (Frisch) elasticity of labor supply of 0.69–as estimated in Pistaferri (2003)–when preferences take the GHH specification.

To compute sectoral shares and their associated factor intensities, we employ annual industry data (compensations of employees, value-added, net operating surplus) provided by the U.S. Bureau of Economic Analysis. Sectoral labor shares (labor intensity) are calculated using the average of three measures constructed in Section 5.1, which adjusts for self-employment and proprietors' income. The capital share, α_i, is then calculated as one minus the labor share in each sector i.

In aggregating all disaggregated sectors into two large sectors, we rank the sectors according to their labor shares in nominal value added and categorize the first half as labor-intensive, and the second half capital-intensive. The share of the labor-intensive sector in the model, γ_l, is such that $\gamma_l = \sum_{i=1}^{N/2} \gamma_i = 0.56$ as in the data, and the share of the capital-intensive sector in value-added is $\gamma_k = 1 - \gamma_l = 0.44$. Factor shares corresponding to the two large sectors, α_l and α_k, are computed as the weighted average of the labor share of each individual sector: $\alpha_l = \sum_{i=1}^{N/2} \gamma_i \alpha_i = 0.16$ and $\alpha_k = \sum_{i>N/2}^{N} \gamma_i \alpha_i = 0.59$.[10]

Since the cross-country spillover parameter is zero, productivities in domestic and foreign economies are stochastically related through the cross-country correlation of shocks $\rho(\varepsilon^H, \varepsilon^F)$. For the purpose of comparing the results with previous works and isolating the contribution of our mechanism from the spillover effects of shock processes, we take Kehoe and Perri's (2002) parameter values as benchmark and set $\text{corr}(\varepsilon^H, \varepsilon^F) = 0.25$. The set of fixed parameter values are presented in Table I (Panel A).

Normalizing the elasticity of the productivity to aggregate shocks in capital-intensive sectors, we set $\eta_k = 1$. The set of parameters to be estimated are given by $(\nu, \theta, \eta_l, b_k, b_l, \rho_z, \sigma_z, \rho_\lambda, \sigma_\lambda,)$. We log-linearize the model around a symmetric steady state. Bayesian methods are used to fit the linearized model to four annual U.S. time series, including two sectoral observations—the real value added in capital-intensive sectors (Y_k) and the real value added in labor-intensive sectors (Y_l)–and two aggregate observations—consumption and investment.[11] Constrained by the availability of sectoral observables, the sample covers the period from 1977 to 2013. Appendix B provides a more detailed description of the data and the prior distributions of the estimation.

Table I (Panel B) reports the estimated parameter values for the model. The parameter ν is estimated to be 0.735, allowing for a significant degree of wealth effect on labor supply. The estimated elasticity of substitution between capital- and labor-intensive goods, θ, is 0.517, and the estimated adjustment cost in the capital-intensive sector is smaller than the adjustment cost in the labor-intensive sector, consistent with findings in Samiengo and Sun (2015). The persistence parameter of technology shock is estimated to be 0.59, implying a quarterly persistence about 0.87, close to the value used in the original Backus et al. (1994). The estimated elasticity of shocks to the labor-intensive sector to the aggregate shock (1.67) implies that the labor-intensive sector is about 70% more responsive to aggregate shocks than the capital-intensive sector. Thus, the labor-

[10] These shares are similar to the values of $\alpha_l = 0.17, \alpha_k = 0.49$ that Cuñat and Maffezzoli (2002) use based on the same exercise for OECD sectoral data covering 24 countries and 28 sectors.

[11] The Bayesian methods have several merits compared to calibration. First, it uses general equilibrium conditions rather than partial equilibrium models or reduced form equations, which improves on the identification as discussed in Leeper and Zha (2000). Second, it performs better than General Methods of Moments methods for small sample estimations.

intensive sector experiences a disproprotionate expansion during booms and a disproportionate contraction during recessions, an observation captured in Figure I.

Table I: Parameter Values

A. Calibrated parameters			
Parameter	Value	Parameter	Value
β	0.95	σ	2
κ	2.75	ψ	2.44
α_l	0.16	α_k	0.59
γ_l	0.56	η_k	1
$\rho(\varepsilon^H, \varepsilon^F)$	0.25		

B. Estimated parameters			
Parameter	Value	Stdev.	[5th, 95th]
ν	0.735	0.095	$[0.613, 0.904]$
θ	0.517	0.086	$[0.499, 0.755]$
b_k	0.114	0.034	$[0.075, 0.191]$
b_l	0.632	0.242	$[0.156, 0.524]$
ρ_z	0.590	0.079	$[0.471, 0.727]$
σ_z	0.014	0.002	$[0.012, 0.016]$
η_l	1.673	0.117	$[1.526, 1.772]$
ρ_λ	0.460	0.076	$[0.373, 0.571]$
σ_λ	0.028	0.003	$[0.028, 0.037]$

Notes: β is the discount factor. σ is the risk aversion parameter in the preference function. κ governs the disutility of labor in the utility function, and ψ is related to the elasticity of labor supply. α_l and α_k are the share of labor in the labor-intensive sector and capital-intensive sector, respectively. γ_l gives the share of labor-intensive sector in the economy. $\eta_i, i = k, l$ is the elasticity of productivity in sector i to the aggregate productivity. $\rho(\epsilon^H, \epsilon^F)$ is the correlation between shocks to home productivity and shocks to foreign productivity. ν governs the persistence of consumption habit formation; θ is the elasticity of substitution between capital-intensive and labor-intensive goods in final goods; b_i stands for the adjustment costs in sector i, $i = k, l$. ρ_z is the persistence parameter in the technology shock process and σ_z is the standard deviation of the shocks to technology. ρ_λ and σ_λ are the persistence parameter and the standard deviation of the preference shock.

4.2 Model Results

Table II reports the simulation results for the two-sector bond economy case and compares it with the corresponding moment in the data. All reported own-economy aggregate statistics are computed from U.S. annual time series over the period 1970-2013. The sectoral statistics are also computed from U.S. sectoral data but for a shorter period of time covering 1977-2013. International correlations refer to the average correlation between a U.S. variable and one of 17 OECD countries—Australia, Austria, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Korea, Netherlands, Norway, Spain, Sweden, and United Kingdom.

The contribution of distinguishing sectors by factor intensity to explaining cross-country co-movement in investment can be seen by comparing Column (2) to Column (7). Even though the model is estimated to target the domestic aggregate and sectoral observations, the international investment comovement is positive (0.38 compared to 0.33 in the data). In contrast, it is negative in the homogeneous sector case (-0.07). Output is also positively correlated in the benchmark case (0.32 compared to 0.52 in the data), and higher than in the homogeneous-sectors case (0.19)—as a result of the now positive investment correlation. In the benchmark model, the international correlation of output (0.32 vs. 0.52 in the data) is greater than that of consumption across countries (0.25 vs. 0.35 in the data).

The relative price of capital to labor-intensive goods behaves broadly in line with the data in terms of its cyclicality, but is less volatile than in the data. Its correlation with detrended GDP in the benchmark economy is 0.64 (compared to 0.70 in the data), and its volatility as a ratio of the output volatility is 0.65 compared to 0.91 in the data. What is reassuring is that one does not need unreasonably large fluctuations in the relative price to generate the aggregate comovement in inputs and outputs across countries.

The sectoral statistics perform well compared to the data. The correlation of the capital-intensive output and domestic GDP is 0.83 in the benchmark economy compared to 0.79 in the data, and the correlation of the labor-intensive output is 0.98 in the model compared to 0.96 in the data. The volatility of sectoral output also closely matches the data. Both in the data and in the model, real value added in labor-intensive sectors are more volatile and more procyclical. What remains to fall short of replicating the data is the procyclical trade balance and the slightly negative labor comovement that obtain under the benchmark economy. Since the estimated parameter for ν is 0.735, the model generates significant income effect of consumption on labor supply. As consumption rises in the Foreign economy in response to a Home productivity shock, the strong income effect bids the Foreign country to reduce labor supply, offsetting the relative price effect on labor. Column (3) shows that reducing the income effect (by setting ν close to zero and hence the preference close to GHH) can raise labor comovement to a positive value (0.11). Reducing the income effect can also generate a mild countercyclical trade deficit (-0.05) due to greater responses in consumption and investment in the Foreign economy.

The mechanism we propose that leads to positive investment comovement and output comovement replies on sectoral heterogeneity in factor intensity, rather than other types of heterogeneity. For example, in Column (4) we set the adjustment costs across sectors to be the same and such that the aggregate investment volatility is comparable to that in the Benchmark case. This change does not alter the international comovement outcome. In addition, Equation (12) implies that lower elasticity of substitution between capital-intensive and labor-intensive goods helps to generate larger relative price effects. Our estimated elasticity implies a low value of $\theta = 0.517$. In Column (5) we experiment with a higher level of substitution with $\theta = 1$. The main results remain the same, despite that the relative price effect is lower weaker (as reflected in a lower $\sigma(P_k/P_l)$). Lastly, for the sake of comparability with existing literature, we shut down the demand shocks in Column (6). It is clear that Home and Foreign countries still positively comove in output and investment, although consumption correlation becomes more positive than the output correlation. Therefore, demand shocks (as they are country-specific shocks and have zero correlation across countries) do not play any material role in driving the investment comovement.

Overall the mechanism we propose appears to be robust to several large changes to the benchmark economy. We view this mechanism to generate endogenously investment comovement as the main contribution of the model—thereby providing an alternative explanation to the one based on highly correlated shocks, or the endogenous incomplete markets model in Kehoe and Perri (2002).

Table II: Simulated RBC moments of the Model Compared with Data

Moments	**Data**	**Benchmark**	**Income effect** ($\nu = 0.001$)	**Adjustment costs** ($b_k = b_l$)	**Elasticity of substitution** (θ=1)	**No demand shock** ($\sigma_\lambda = 0$)	**Homogeneous sectors**	**Adding nontradables** Data	Model
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
A. Aggregate Statistics									
Volatility									
$\sigma(y^H)$	2.24	2.45	2.83	2.46	2.37	2.45	2.39	2.24	3.09
$\sigma(tby^H)$	0.62	0.71	0.53	0.78	0.67	0.30	1.18	0.62	1.44
$\sigma(c^H)/\sigma(y^H)$	0.83	0.55	0.59	0.54	0.55	0.38	0.53	0.83	0.43
$\sigma(i^H)/\sigma(y^H)$	3.19	3.45	2.99	3.45	3.38	3.28	3.75	3.19	4.02
$\sigma(l^H)/\sigma(y^H)$	0.99	0.28	0.42	0.29	0.30	0.26	0.28	0.99	0.50
Domestic Comovement									
$\text{corr}(c^H, y^H)$	0.68	0.60	0.88	0.59	0.58	0.91	0.54	0.68	0.86
$\text{corr}(i^H, y^H)$	0.87	0.94	0.95	0.93	0.94	0.98	0.82	0.87	0.84
$\text{corr}(l^H, y^H)$	0.28	0.89	0.99	0.90	0.90	0.95	0.91	0.28	0.93
$\text{corr}(tby^H, y^H)$	-0.56	0.22	-0.05	0.26	0.10	0.41	0.11	-0.56	0.27
International Correlations									
$\text{corr}(y^H, y^F)$	0.52	0.32	0.31	0.30	0.32	0.31	0.19	0.52	0.28
$\text{corr}(c^H, c^F)$	0.35	0.25	0.29	0.24	0.22	0.70	0.18	0.35	0.37
$\text{corr}(i^H, i^F)$	**0.33**	**0.38**	**0.23**	**0.40**	**0.27**	**0.33**	**-0.07**	**0.33**	**0.25**
$\text{corr}(l^H, l^F)$	0.42	-0.09	0.11	-0.08	-0.03	-0.04	0.06	0.42	0.26
B. Sectoral Statistics									
Volatility									
$\sigma(y_k^H)/\sigma(y^H)$	0.58	0.75	0.73	0.70	0.70	0.75	N/A	1.25	0.92
$\sigma(y_l^H)/\sigma(y^H)$	1.75	1.24	1.24	1.25	1.36	1.24	N/A	2.39	1.72
$\sigma(P_k/P_l)/\sigma(y^H)$	0.91	0.65	0.63	0.63	0.52	0.64	N/A	2.06	1.59
Correlations with Domestic Output									
$\text{corr}(y_k^H, y^H)$	0.79	0.83	0.85	0.86	0.84	0.84	N/A	0.20	0.45
$\text{corr}(y_l^H, y^H)$	0.96	0.98	0.98	0.98	0.98	0.98	N/A	0.91	0.98
$\text{corr}(P_k/P_l, y^H)$	0.70	0.64	0.68	0.68	0.67	0.65	N/A	0.56	0.75
$\text{corr}(s_k^H, y^H)$	-0.82	-0.67	-0.70	-0.74	-0.73	-0.67	N/A	-0.54	-0.58

Notes: The statistics in the data column (1) are calculated from U.S. annual time series, 1970-2013—with the exception of international correlations, which are calculated using data from the U.S. and 17 OECD countries. The data statistics are based on logged (except for net export to GDP ratio) and HP-filtered data with smoothing parameter of 100. The model statistics are computed using simulated data (in log and HP-filtered) from a simulation of the model economy of 1000 periods. Parameters are taken from the benchmark case in Table I. Column (1)-(6) are the two-sector bond economy case, (7) is the homogeneous sectors case, and (8)-(9) are for assessing the model with nontradable sectors as in Section 4.3.

4.3 Sensitivity Analysis: Nontradable Goods

Since nontradable goods comprise a large share of an economy's output, we incorporate a domestic nontradable sector in each country into the existing framework. Country j's production technology combines intermediate tradable goods Y_T^j and nontradable goods Y_N^j to form a unit of final good, such that

$$Y^j(s^t) = \left[\gamma_T^{\frac{1}{\zeta}} \left(Y_T^j(s^t)\right)^{\frac{\zeta-1}{\zeta}} + (1-\gamma_T)^{\frac{1}{\zeta}} \left(Y_N^j(s^t)\right)^{\frac{\zeta-1}{\zeta}}\right]^{\frac{\zeta}{\zeta-1}}, \tag{16}$$

where $Y_N^j(s^t)$ and $Y_T^j(s^t)$ denote j's aggregate nontradable and tradable output at s^t. Let the gross output of the nontraded good in country j be:

$$Y_N^j(s^t) = A_N^j(s^t) \left(K_N^j(s^t)\right)^{\alpha_N} \left(N_N^j(s^t)\right)^{1-\alpha_N}, \tag{17}$$

where $K_N^j(s^t)$ is the aggregate capital stock in the nontradable sector, and $N_N^j(s^t)$ is the labor used in the nontradable sector in j, at s^t, and α_N is the capital share in the nontradable goods sector. The productivity shock to nontradable goods sector follows: $\log(A_{Nt}^j) = \rho_N \log(A_{N,t-1}^j) + \varepsilon_{N,t}^j$, where $\varepsilon_{N,t}^j$ is an *i.i.d.* zero-mean normal process with standard deviation given by σ_N and uncorrelated across countries: corr$(\varepsilon_{N,t}^H, \varepsilon_{N,t}^F)$=0. The overall consumer price index becomes:

$$P_t^j = \left[\gamma_T \left(P_{T,t}^j\right)^{1-\zeta} + (1-\gamma_T) \left(P_{N,t}^j\right)^{1-\zeta}\right]^{\frac{1}{1-\zeta}}, \tag{18}$$

where $P_{T,t}^j$ is the same as Eq. (6), and is normalized to 1. In equilibrium, both p_{it} and the relative price of nontraded to traded goods in j at t, $P_{N,t}^j$, are determined endogenously. Investment in any tradable sector i, $x_i^j(s^t)$, or the nontradable sector N, $x_N^j(s^t)$, is $x_u^j(s^t) = \left[\sum_{k=1}^m \gamma_i^{\frac{1}{\theta}} \left(z_{ki}^j(s^t)\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}$, where $u = i, N$. The additional market clearing condition of the non-traded sector requires that the output of nontradable goods in j must equal the domestic consumption of that good:

$$Y_{N,t}^j = C_{N,t}^j. \tag{19}$$

The domestic labor market clears when $\sum_{i=1}^m N_{it}^j + N_{Nt}^j = N_t^j$.

Calibrated to the data that include capital-intensive and labor-intensive tradable sectors and nontradable sectors, we have $\alpha_N = 0.35$ and $\gamma_N = 0.45$ for the nontradable sector.[12] Dividing the tradable sectors into capital and labor-intensive sectors (in a similar fashion as before), we now have γ_k=0.10, α_l=0.61 and α_k=0.25. The existing literature focuses on low values of the elasticity

[12] The tradable vs. nontradable sectors definition follows Stockman and Tesar (1995).

of substitution ζ, ranging from 0 to 1 for industrialized countries (see (Coeurdacier 2009)), and we adopt $\zeta = 0.55$ as in Stockman and Tesar (1995). The other previously calibrated parameters remain the same as before. Given these parameters fixed, we estimate the rest of the parameters (i.e. $\{\nu, \theta, \eta_l, b_k, b_l, b_N, \rho_z, \sigma_z, \rho_\lambda, \sigma_\lambda, \rho_N, \sigma_N\}$) using Bayesian methods similarly as before. Five observable domestic targets are used in this case: three sectoral observations including the real value added in capital-intensive tradable sectors, in labor-intensive tradable sectors and in nontradable sectors (Y_k, Y_l, Y_N), and two aggregate observations—consumption and investment. Appendix B provides further details on the estimation.

The last panel of Table II compares the data moments with the model-generated moments. Since detailed sectors in the data are now divided into three sectors, the sectoral statistics reported in the lower panel in Column (8) differ from the data moments in Column (1). The aggregate data moments, however, are unchanged. These results show that incorporating nontradable sectors into the model does not alter our key results: the cross-country output and investment correlations are still positive, although the composition effects operating through the traded sectors is weakened (also reflected in a smaller corr(s_k^H, y^H) both in the data and in the model). Meanwhile, cross-country labor input comovement now turns positive with a correlation of 0.25. This is because of the existence of the nontradable sector which complements the tradable sector in production (as shown in Equation (16)). The volatilities of capital- and labor-intensive sectors in the case of three sectors are higher compared to the two-sector case, as the nontradable sector is much less volatile compared to the tradable sectors in the data (the standard deviation of detrended real value added of nontradable sectors is about half the standard deviation of tradable-sector real value added). The volatility of the relative price between capital-intensive goods and labor-intensive goods is also higher in the three-sector case, and the model-generated moment reflects this change well. Importantly, the conditions for our key transmission mechanism are unchanged in the three-sector case: the labor-intensive sector is significantly more responsive to the business cycles, and the relative price between capital and labor-intensive goods remains strongly procyclical both in the data and in the model.[13]

[13] Although not reported here (but available upon request), it turns out that the Backus-Smith correlations are also consistent with the data, in this model. In a multi-sector setting, there is a strong and negative correlation between the real exchange rate and the consumption ratio (-0.85 compared to -0.71 in the data for the U.S.). However, we do not emphasize this result here as variations in the real exchange rate is driven by fluctuations in the relative price of nontraded to traded goods, whereas evidence indicates that real exchange rate fluctuations are mostly driven by fluctuations in tradable goods. However, in this model, a positive productivity shock can lead to an appreciation of the real exchange rate in the domestic economy.

5 Evidence on the Transmission Mechanism

In this section, we assess whether the key transmission mechanisms are consistent with evidence from the data, and in turn provide new cyclical properties of sectoral data based on a capital/labor-intensive differentiation. Different from Figure II in which all industries are recast into two large sectors, the regression analyses presented here are at the most disaggregated industry level in order to use all available information. We are interested in whether the differential responses of sectors associated with business cycle fluctuations as predicted by the model conform with the data. As discussed below, since the comparable sectoral data across countries are only available for a limited time period, conducting a time series analysis of sectoral responses to well-identified country-specific shocks would not be feasible. In what follows, we focus on the correlations of sectoral variables with business cycles without identifying any causal effects.

5.1 Data and Measurement

Data Description. The data that we use for sectoral production and prices in the U.S. come from two sources. The first is U.S. BEA's Industry Account Dataset, which includes detailed annual industry production data (value added, real value added, employment, wage compensation) for 61 private sectors at the most disaggregated level (corresponding to NAICS 2-4 digit level) for the period of 1977-2013. Second, to show that our results are not driven by particular sectors—such as services or construction—we check our core results using the NBER-CES Manufacturing Industry Database, which provides manufacturing input and output data at the 6-digit NACIS level for the period of 1958-2005. Data at the highest level of disaggregation are used to obtain higher precision when classifying sectors according to their factor intensity.[14] Sectoral price indices are constructed as the ratio between sectoral nominal value added and real value added. Highly disaggregated U.S. trade data are provided by the U.S. International Trade Commission (USITC). The trade value data are available at quarterly frequency for a somewhat limited period: 1989Q1-1996Q4 for 4-digit SIC sectors, and 1997Q1-2011Q4 for 6-digit NAICS sectors.

Industry data for countries other than the U.S. are obtained from the OECD STAN dataset, which publishes annual estimates of industry input and output at ISIC 2-4 digit level for 31 countries. Detailed industry data is available at different levels of disaggregation for different countries.

[14] An important point emphasized in Schott (2003) is that higher disaggregation, within the same standard industry, can lead to greater heterogeneity in input intensities. The standard industry classification groups goods roughly according to the similarity in their end-use (i.e. goods that are close substitutes rather than manufactured with similar factor inputs), "a procedure not necessarily consistent with the conceptualization of goods in the factor proportions framework" (Schott, 2003). For this reason, one should always use the most disaggregated sectoral data when studying issues related to factor proportions.

In order to construct a set of internationally comparable sectors, we aggregate detailed industries to have a total of 32 sectors at the 2-3 digit ISIC level for each country. Compared to the U.S. data, the cross-country data span over a much more limited time period (e.g. 17 years for some major industrial economies).[15]

Measuring Sector-Specific Labor Intensity. The commonly adopted measure of labor intensity is the share of employment compensation in nominal value-added (net operating surplus). The problem with this approach is that the proportion of income perceived by the self-employed as a remuneration of their own work is recorded as capital income rather than labor income. To adjust for this concern, we also consider two alternative measures. Data on proprietors' income and self-employment are available from BEA; however, they are recorded at a much higher aggregated level. As an approximation, we assume proprietor's income to employment compensation ratios and shares of self-employment are the same across industries within the same sectoral category. Lacking further information on how to apportion proprietor's income (as it includes both labor and capital income components), we construct the second measure by apportioning proprietors' income equally to labor and capital and adjusting the previous measure of capital share accordingly. The third measure assumes that self-employed workers would pay themselves the same wage that they could otherwise earn in the same industry, and adjusts the labor shares by dividing them by the sectoral share of employees in total employment, a method similar to Gollin (2002). As none of these measures are perfect, we take the average of the three to obtain the final labor shares. The resulting estimates are then averaged across the sample period to obtain time-invariant labor shares. When using the NBER manufacturing data, the labor share of industry nominal value added is calculated simply as total payroll over nominal value added, as there is no additional information on self-employment or proprietor's income. More detailed descriptions of the data and methodologies are provided in Appendix A.

5.2 Domestic Composition Effects: Evidence Using U.S. Data

Our theory predicts that during booms: (1) sectors with higher labor intensity tend to expand more (i.e. higher increases in output and input); (2) the relative price of sectors that use labor input more intensively falls more; and (3) net exports rise with the labor intensity of a sector.

To examine these relationships systematically across all sectors, the following regression is

[15]For example, reliable industry data from OECD STAN only exist at the annual frequency for 1991-2008 for Germany, France, Italy and UK.

performed using detailed sectoral data:[16]

$$\Delta X_{i,t} = \beta_0 + \beta_1 \Delta \ln Y_t + \beta_2 \Delta \ln Y_t \times S_i + f_i + \varepsilon_{i,t}, \tag{20}$$

in which the dependent variable $\Delta X_{i,t}$ stands for the variable of interest: (1) the growth rate of real value added in sector i in year t, denoted $\Delta \ln y_{i,t}$; (2) the growth rate of employment in sector i, $\Delta \ln l_{i,t}$; (3) the growth rate of real investment in sector i, $\Delta \ln i_{i,t}$; (4) the growth rate of the price index of output in sector i relative to the consumer price index, $\Delta \ln p_{i,t}$, and (5) the change in net export-to-GDP ratio in sector i, $\Delta nx_{i,t}$. The independent variables include: the economy-wide real GDP growth rate $\Delta \ln Y_t$ (as an indicator of business cycles), an interaction term between real GDP growth and the labor intensity in sector i, $\Delta \ln Y_t \times S_i$; and industry fixed effects denoted by f_i. Estimates of equation (20) are reported in Table III, with each panel corresponding to results based on a different dependent variable.

Table III: Sectoral Cyclicality and Labor Intensity

Dependent variable:	A. $\Delta \ln y_{i,t}$		B. $\Delta \ln l_{i,t}$		C. $\Delta \ln i_{i,t}$		D. $\Delta \ln p_{i,t}$		E. $\Delta nx_{i,t}$
	All Sectors SIC 2-3d (1977-2013)	Manu. NAICS 6d (1958-2005)	All Sectors SIC 2-3d (1977-2013)	Manu. NAICS 6d (1958-2005)	All Sectors SIC 2-3d (1977-2013)	Manu. NAICS 6d (1958-2005)	All Sectors SIC 2-3d (1977-2013)	Manu. NAICS 6d (1958-2005)	Tradables NAICS 6d (1997:1-2011:1)
$\Delta \ln Y_t$	-0.091	1.197	-0.161	-0.079	1.116	-1.198	1.404	-0.188	-1.565
	(-0.18)	(2.65)	(-0.32)	(-0.34)	(1.51)	(-2.22)	(3.63)	(-1.67)	(-3.39)
$\boldsymbol{\Delta \ln Y_t \times S_i}$	**1.944**	**2.187**	**1.598**	**2.997**	**2.409**	**8.903**	**-2.001**	**-1.382**	**3.074**
	(2.62)	(2.27)	(2.20)	(5.26)	(2.31)	(7.21)	(-3.67)	(-2.65)	(2.85)
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	2013	21330	2013	21802	1980	21802	1944	21330	21253

Notes: The dependent variable is the percentage change of real value added in sector i at time t in Panel A, the percentage change of employment in Panel B, the percentage change of real investment in Panel C, the percentage change of price (normalized by aggregate price index) in Panel D, and the change of the net export-to-GDP ratio from U.S. to EU15 economies in Panel E. Panel A-D report coefficient estimates based on two datasets each: U.S. industry account database, which provides the sectoral production, price and labor intensity data covering 61 2-3 digit SIC private sectors in the U.S. for 1977-2010; NBER-CES manufacturing dataset, which provides the sectoral production, prices and labor intensity data covering 428 6-digit NAICS manufacturing sectors for the period of 1972-2005. The datasource for Panel E is US international Trade Commission, which provides import export data covering 382 6-digit NAICS sectors for the period 1997Q1-2011Q1. Robust t-statistics are reported in the bracket.

In principle, the domestic compositional and price effects should apply to all sectors, the reason for which we report results using information for all available sectors. However, to show that these results are not driven by a specific set of sectors, such as nontradables, services or construction sectors, we also examine manufacturing sectors alone. Since manufacturing production data are available at more disaggregated levels (NAICS 6-digit), measures of factor intensity are more

[16]Including more lags in regression (20) does not change the results in any significant ways and coefficients of variables with lags are not significant in most cases.

precise—addressing Schott's (2003) concern—and manufacturing data allow for more observations (1958-2005).

We are particularly interested in the regression coefficient of the interaction term between the sector's factor intensity with U.S's real GDP growth. Table III Panel A show that the estimate of β_2 is positive and statistically significant, implying that positive real GDP growth in the U.S. is associated with a larger rise in sectors that are more labor-intensive. To illustrate the magnitude of these effects, consider two sectors—one with labor intensity of 40 percent and the other with 85 percent (roughly corresponding to the weighted average labor shares of the bottom and top half sectors in our sample). The left column of Panel A suggests that a one percent rise in US GDP growth is associated with an increase of 0.7 percent in real value added of the relatively capital-intensive sector and a much larger increase of 1.6 percent in the relatively labor-intensive sector.

Similarly, estimates in Panel B and C indicate that more labor-intensive sectors are associated with more increase in employment and investment during economic booms and larger decrease in employment and investment during recessions. The dependence of the differential responses of sectoral employment/investment on their labor intensity is significant. In the previous example of two representative sectors, these estimates imply that the employment of the representative capital-intensive sector increases by 0.5 percent in response to a one percent increase in GDP, while the employment of the labor-intensive sector rises by 1.2 percent— more than double the response of the capital-intensive sectors. The investment of the capital-investment sector rises by 2.1 percent, compared to 3.2 percent increase in the labor-intensive sector.

Third, the estimates of β_2 for Panel D is significant and negative, indicating that a U.S. boom is associated with greater declines in the prices of sectors that are more labor-intensive. Again, turning to the two large sectors in the previous example, the left column suggests that a one percentage point rise in US growth is associated with an increase of 0.6 percent points of the price of the representative capital-intensive sector, and a drop of 0.3 percentage points in the labor intensive sector.

These differential sectoral responses to the business cycle are statistically significant not only economy-wide, but also among manufacturing sectors, as shown in the right column of each panel, although the magnitude of the difference is smaller. Using a similar example (labor intensity correspond to 0.34 and 0.51 in the representative capital and labor-intensive sector), the real value added of an average labor-intensive manufacturing sector increases by 2.31 percent and its employment (investment) increase by 1.45 (3.38) percent in response to a one percent increase in real GDP growth, compared to 1.94 and 0.94 (1.83) percent of an average capital-intensive manufacturing sector.[17] Related, the (normalized) price of labor intensive sector drops by 0.54 percent, while the price of capital intensive sector decreases by 0.38 percent.

Another implication of the model that captures the international transmission mechanism is the behavior of net exports. While we know that the trade balance as a whole is countercyclical, a key prediction of the model is that the degree of cyclicality varies with labor intensity: the more labor-intensive is a sector, the more procyclical is its net exports. These predictions are confirmed by Panel E. On average, the aggregate trade balance is indeed countercyclical ($\beta_1 < 0$). The coefficient $\beta_2 > 0$, however, shows that net exports tend to increase more the more labor-intensive is a sector. In fact, among the 382 tradable sectors in our dataset, about 24% of tradable sectors' net exports respond positively to business cycle booms.

5.3 International Transmission: Evidence Using Cross-Country Data

Domestic business cycles are associated with not only domestic compositional changes but also with foreign compositional changes and a change in the international relative price of capital and labor-intensive goods. We proceed to examine whether the international transmission mechanism is reflected in other countries' compositional changes. The model implies that (1) domestic booms are associated with a greater expansion in labor-intensive sectors, but a foreign boom is associated with a domestic expansion in capital-intensive sectors; (2) booms in either domestic or foreign economies are associated with a fall in the relative price of labor-intensive goods. To test these implications, we examine the cyclical behavior of sectoral output and prices in response to domestic and foreign business cycles by running the following regression:

$$\Delta \ln X_{ict} = \beta_0 + (\beta_1 + \beta_2 S_i)\Delta \ln Y_{c,t} + (\beta_3 + \beta_4 S_i)\Delta \ln Y_{-c,t} + (\beta_5 + \beta_6 S_i)\Delta \ln Y_{it} + f_{ic} + \varepsilon_{ict}, \qquad (21)$$

where ΔX_{ict} denotes the growth rate of real value added in sector i of country c in year t, $\Delta \ln y_{ict}$, and the price of sector i in country c relative to the consumer price index in that country, $\Delta \ln p_{ict}$. $\Delta \ln Y_{c,t}$ and $\Delta \ln Y_{-c,t}$ respectively denote the GDP growth rate in country c and the average GDP growth rate in the other OECD countries excluding country c. $\Delta \ln Y_{it}$, the average growth rate of real value added across all countries in sector i, is included to control for the world-wide sector-specific shocks, and f_{ic} is country-industry fixed effect.

Table IV displays the regression results of equation (21). The second and third rows show how sectoral outputs and inputs (in Column (1)-(3)) respond to domestic business cycles, and the fourth and fifth rows demonstrate how they respond to foreign business cycles. Interestingly, sectors

[17] Labor intensity in this case is calculated as total payroll as share of value of shipment (also consider raw material as an input). Thus the resulting labor share is much smaller: 0.14 for capital intensive sector and 0.25 for labor intensive sector.

Table IV: Cross-country Observations (31 OECD countries, 1975-2010)

Dependent variable:	$\Delta \ln y_{ict}$	$\Delta \ln l_{ict}$	$\Delta \ln i_{ict}$	$\Delta \ln p_{ict}$
	(1)	(2)	(3)	(4)
$\Delta \ln Y_{c,t}$	0.649	0.321	1.628	0.396
	(5.78)	(3.06)	(3.08)	(2.95)
$\boldsymbol{\Delta \ln Y_{c,t} \times S_i}$	**0.607**	**0.335**	**0.808**	**-0.216**
	(3.92)	(2.43)	(1.13)	(-1.16)
$\Delta \ln Y_{-c,t}$	-0.560	0.234	1.515	1.384
	(-3.28)	(1.63)	(1.98)	(6.42)
$\boldsymbol{\Delta \ln Y_{-c,t} \times S_i}$	**-0.652**	**-0.828**	**-2.369**	**-1.465**
	(-2.54)	(-4.24)	(-2.21)	(-4.83)
$\Delta \ln Y_{i,t}$	0.537	-0.170	-1.322	-1.076
	(6.82)	(-3.01)	(-4.26)	(-11.28)
$\Delta \ln Y_{i,t} \times S_i$	0.628	0.613	2.736	0.909
	(5.77)	(7.92)	(.22)	(6.88)
Country FE	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes
Observations	19,696	10,683	14,742	15,888

Notes: Column (1)-(3) shows the regression coefficients where the dependent variable is the percentage change of real value added, the percentage change of employment, and the percentage change of investment in sector i of country c at time t, respectively. The dependent variable of Column (4) is the percentage change of price (normalized by aggregate price index). Labor intensity is measured as the share of labor cost in value-added (minus net operation profit and taxes less subsidies). Data source is OECD STAN dataset for 31 OECD countries and 32 sectors for the period 1975-2010, although many countries only have observations from 1992. t-statistics are reported in the brackets.

expand by more the more labor-intensive they are ($\beta_2 > 0$) in response to domestic booms, while they contract by more the more labor-intensive they are in response to foreign booms ($\beta_4 < 0$). This concords with the international transmission mechanism that a positive home productivity shock tends to increase relatively more the foreign country's capital-intensive sector and home country's labor-intensive sector.

Column (4) of Table IV shows that both domestic and foreign booms are associated with a decrease in the relative price of labor-intensive goods compared to the price of capital-intensive goods ($\beta_2, \beta_4 < 0$). When examined all together, this evidence is consistent with the view that there is a transmission mechanism of business cycles that works through changes in the relative prices that are associated with composition effects. In particular, positive shocks abroad lead to increase in the prices of capital-intensive goods, motivating investment and capital inflow and stimulating output and input at home. Through this channel, shocks are positively propagated across countries.

6 Conclusion

This paper integrates factor-proportions differences across sectors into a two-country stochastic growth model. Endogenous domestic and foreign composition effects, brought about by international trade, lead to a positive transmission of country-specific productivity shocks across countries that, under conditions met by the data, can dominate the negative transmission of shocks via resource shifting across countries that underlies standard models. The new transmission mechanism occurs through changes in the relative price of capital and labor-intensive goods, and key elements to this process receive empirical support.

In this paper we bring to bear the potentially illuminating act of separating labor-intensive sectors from capital-intensive sectors in investigating facts about business cycles. Composition changes is at once an empirical regularity at the business-cycle frequency—and not only a long-run phenomenon. New empirical findings on the distinctive behavior of capital and labor-intensive industries may serve to be a starting point for a more thorough theoretical and empirical investigation of the nature of sectors marked by differential factor intensities—both in the domestic and international business-cycle context.

Appendix A Data

Sectoral Statistics of Production

The sectoral evidence of employment and real value-added for the U.S. are based on data obtained from the BEA Industry Account Dataset, which provides annual series of nominal/real (chain-type, base year 2005) value-added, price index and components of value-added at NAICS 2-4 digit level from 1977 to 2013. There are 61 private sectors at the most disaggregated level, among which 38 are classified as tradable sectors according to Stockman and Tesar's (1995) definition of tradable sectors.[18] We use all private sectors in most of our empirical studies, but also confirm that our sectoral evidence does not vary significantly once we limit our sectors to tradables only.

Capital share in value-added is calculated as one minus labor share in the corresponding sector. There are three methods to construct sectoral labor shares. First, following the standard assumption of Cobb-Douglas production function and competitive markets, time-average labor share (ls_1) at the detailed industry level is constructed as $ls_1 = \frac{1}{T}\sum_{t=1}^{T} ls_t$, where ls =compensation of employees/(value-added - taxes less subsidies). With this approach, the proportion of income perceived by the self-employed as a remuneration of their own work is recorded as capital income rather than labor income. To adjust for this problem, we consider two alternative measures. BEA provide data on proprietors' income and self-employment; however, they are recorded at a more aggregated level (NAICS 2-digit). As an approximation, we assume industries within the same category have the same proprietors' income to employment compensation ratios and also the same share of self-employment. Owing to a lack of further information on how to apportion proprietor's income (as it includes both labor and capital income components), we construct the second measure by apportioning proprietors' income equally to labor and capital and adjusting the previous measure of capital share accordingly. That is, ls_2=1-(compensation of employees+proprietor's income $\times$ 0.5)/(value-added - taxes less subsidies). To obtain the third measure, we assume that self-employed workers would pay themselves the same wage that they could otherwise earn in the same industry. Thus, ls_3=$ls_1\times$(full-time equivalent employment+self-employment)/self-employment. The average of these three measures, $(ls_1 + ls_2 + ls_3)/3$, is then used as our final measure of labor shares.

All sectors are then recast into one of the two larger sectors: labor-intensive sector if its capital share is lower than the median and capital-intensive sector otherwise. Real/nominal value-added, and numbers of employees are summed up to two sectors. Price indices for the labor-intensive sector and the capital-intensive sector are then calculated by dividing the aggregated nominal value-added over the aggregated real value-added.

It is important to note that sectoral and aggregate quantities published by BEA are all based

[18] This includes agriculture, manufacturing, mining, wholesale and retail trade and transportation.

on Fisher quantity (chained) index (Q_t^F), which is the geometric mean of the Laspeyres quantity index (Q_t^L) and the Paasche quantity index (Q_t^P),

$$Q_t^F = (Q_t^L Q_t^P)^{\frac{1}{2}}, Q_t^L = \frac{\sum_i^N p_{it-1} q_{it}}{\sum_i^N p_{it-1} q_{it-1}}, Q_t^P = \frac{\sum_i^N p_{it} q_{it}}{\sum_i^N p_{it} q_{it-1}}$$

where p_{it} and q_{it} are the price and quantity of goods i at time t. Therefore, GDP components in Chained prices are not additive. We need to construct industry real value-added in *constant prices* first in order to calculate the real quantities at more aggregated level—in capital-intensive and labor-intensive sectors. It is easy to show that the growth rate of GDP in chained prices can be decomposed by[19]

$$\frac{Y_t^F}{Y_{t-1}^F} - 1 = Q_t^F - 1 = \sum_i^N w_{it-1}^F \left(\frac{q_{it}}{q_{it-1}} - 1\right) = \sum_i^N g_{it}^F,$$

where $g_{it}^F = w_{it-1}^F(\frac{q_{it}}{q_{it-1}} - 1)$ is sector i's additive growth contribution published by BEA and w_{it-1}^F is the Fisher weight such that $Q_t^F = \sum_i^N w_{it-1}^F(\frac{q_{it}}{q_{it-1}})$. Therefore, instead of using the published disaggregated real value-added data directly, we sum up each sector's contribution to growth to obtain the growth contribution of two larger sectors, $g_{Kt} = \sum_{i \in K\text{Sector}} g_{it}^F$ and $g_{Lt} = \sum_{i \in L\text{Sector}} g_{it}^F$. The real value-added of each of these two larger sectors is then calculated according to $Y_{jt} = Y_{jb} + \sum_{s=b}^t RGDP_{s-1} g_{js}$ after the base year and $Y_{jt} = Y_{jb} - \sum_{s=t}^{b-1} RGDP_s g_{js+1}$ before the base year, where b denotes the base year 2005 and $j = K$ or L.

Other countries' industry data are taken from the OECD STAN dataset, which publishes annual estimates of sectoral input and output data at ISIC 2-4 digit level for 31 countries. However, only for a smaller set of countries and at the relatively more aggregated sector level, we are able to construct a set of internationally comparable industries. In the end, we have a much smaller number of industries—32 industries—at 2-3 digit ISIC level for each country. Another drawback of the OECD STAN dataset is even though the dataset dates back to 1970, most major industrial countries do not have detailed sectoral data before 1992. For each country, we estimate the country-sector specific capital share as 1-labor cost/(value-added - net operation profit - taxes less subsidies).[20] To be consistent with our model, where goods across countries within the same sector have identical factor proportions, we use the cross-country time-average from these calculations. The detailed industries are then divided into two larger sectors according to their fixed capital shares, and input and output estimates are aggregated accordingly. The evidence on the relation-

[19] Also see Dumagan (2009).

[20] Similar to the evidence in the U.S., the estimated capital shares also vary substantially, ranging from 0.08 to 0.83.

ship between capital-intensive sector shares and the business cycles for OECD countries are given in Table A.1.

Table A.1: Evidence on the Countercyclical Share of Capital-Intensive Sectors, OECD economies

country	$\rho(\frac{l_K}{l}, y)$	$\rho(\frac{y_K}{y}, y)$	$\sigma(y_l)/\sigma(y_k)$
Austria	-0.561	-0.703	1.604
Canada	-0.434	-0.737	1.309
Denmark	-0.482	-0.365	0.962
Finland	-0.893	-0.933	3.057
France	-0.393	-0.390	1.259
Germany	-0.067	-0.325	0.977
Italy	-0.286	-0.487	1.379
Netherlands	-0.528	-0.696	2.007
Norway	-0.651	-0.606	1.336
Spain	-0.845	-0.811	1.835
UK	-0.656	-0.582	1.502
USA	-0.580	-0.870	2.101
average	**-0.531**	**-0.625**	**1.611**

Trade Data

Disaggregated quarterly U.S. trade data at the 6-digit NAICS level are available from the website of the US International Trade Commission (USITC) for the period 1997Q1 to 2011Q4, and are available at the 4-digit SIC level from the period 1989Q1 to 2001Q4. The trade data is then merged with NBER manufacturing industry data, which provides information on capital shares in industry value-added that is used to categorize the detailed trading sectors into different groups (for most cased, we consider two large groups—capital and labor-intensive sectors). Therefore, only a subset of the trading sectors (i.e. manufacturing sectors) are included.[21] Trade balance is defined as the difference between export and import as a ratio of GDP. Export and import data are seasonally adjusted using Census X-12 method.

We also obtain detailed industry price data of imports and exports from the USITC. Import and export price indices for capital and labor-intensive sectors are constructed as the unweighted average of price changes of all disaggregated industries within each of the two large groups, excluding outliers.

Aggregate Statistics

For the economy-wide statistics reported in Table II, we use annual constant price based NIPA series of GDP, private consumption, private fixed asset formation, export and import from the U.S.

[21] Annual sectoral trade data is also available in Feenstra's world trade dataset. However, since the data is based on 4-digit SITC72 level, and there is no reliable way to construct capital intensity at this level, this information is not utilized in this paper.

Bureau of Economic Analysis. Employment data for the U.S. are obtained from the U.S. Bureau of Labor Statistics. The international comovement statistics are calculated using the average statistics between U.S. and individual industrial countries including Australia, Austria, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Korea, Netherlands, Norway, Spain, Sweden, and United Kingdom. For these countries, all data series are obtained from the Economic Cooperation and Development (OECD) National Account Statistics and Population and Employment Statistics. The sample period begins at 1970 and ends at 2013.

Appendix B Estimation

We adopt Bayesian methods to estimate the log-linearized model described in Section 2 by fitting it to annual U.S. data.The Bayesian methods have several merits compared to calibration. First, it uses general equilibrium conditions rather than partial equilibrium models or reduced form equations, which improves on the identification as discussed in Leeper and Zha (2000). Second, it performs better than General Methods of Moments methods for small sample estimations.

Appendix B.1 Benchmark Model

Calibrated parameters

A number of parameters are kept fixed throughout the estimation. We obtain the values of these parameters by calibrating the model to match the steady-state values of some observables. The discount factor β is set to be 0.95, which implies a nominal interest rate of 5 percent annually. The risk aversion parameter σ is set at 2 as standard in the literature. ψ is set at 2.44 and κ equals 2.75. consistent with evidence on elasticity of labor supply as in Pistaferri (2003). The share of capital-intensive sector in total value added, $\gamma_k = 0.44$, as calculated from the data. Capital intensities in capital-intensive and labor-intensive sectors are computed as $\alpha_k = 0.59$ and $\alpha_l = 0.16$ respectively, as explained in the main text. To match the sample mean of the investment-output ratio, the depreciation rate delta is set to 0.1. The correlation across country is set at 0.25 to be comparable with existing studies.

Data

We estimate the rest of the structural parameters: $\{\nu, \theta, \eta_l, b_k, b_l, \rho_z, \sigma_z, \rho_\lambda, \sigma_\lambda\}$, and use U.S. observations on real consumption, real private domestic investment, real value added of capital-intensive sector and labor-intensive sector ($\{C,\ I,\ Y_k,\ Y_l\}$) from 1977-2013 as four targets. Consumption and investment data are obtained from from U.S. BEA NIPA dataset. Data series on sectoral real value added output are obtained from BEA industrial production database. All data series are HP-filtered with a smooth parameter of 100. We then obtain the cyclical components of each variable, and match them to the difference between the logarithm of the corresponding model variables and their steady states.

The Priors

We choose priors of the estimated parameters in a wide domain that is comparable to values commonly used in literature, such as Smets and Wouters (2003a). In particular, we use Beta distribution for all the parameters with domain between 0 and 1, which applies to the persistence parameters of the shock processes ρ_λ and ρ_z, and the preference parameter ν which disciplines the income effect of labor supply. The prior mean for ν is set at 0.5, which is between the extreme values in the case of GHH ($\nu = 0$) and KPR ($\nu = 1$). We use the inverse gamma distribution for the parameters with positive values, including the standard deviation of technology shock σ_λ and preference shock σ_z, the elasticity of shocks in the labor intensive sector to the aggregate shock η_l, and the elasticity of substitution between labor-intensive and capital-intensive goods in final sector, θ. The choices of means and variances of shock persistence and volatility are quite uninformational. The prior mean for η_l is chosen such as the aggregate shodk has the same effect on both labor- and capital-intensive sectors. We use normal distribution for b_k and b_l. The structural parameters to be estimated and their associated prior distributions are listed in Table A.2.

The posteriors

Table A.2 also summarizes the estimates of structural and shock parameters at the posterior mode with 90% probability intervals (the last column). The preference parameter ν is estimated to be 0.735, which implies a fairly large income effect of consumption on labor supply. The estimated elasticity is 0.517. The estimated persistence for technology shock is 0.590, a rather low persistent level. The adjustment cost of investment in capital-intensive sector is lower than that in the labor-intensive sector. The sensitivity of shocks to production in the labor-intensive sector is 67% higher than these in the capital-intensive sector, consistent with the observation that labor-intensive sectors tend to disproportionately expand (contract) during booms (busts).

Appendix B.2 The Model with Nontradables

This section shows the priors and posteriors of the estimated parameters in the model augmented with nontradable sectors. As we now have one more shock process—the productivity shock to the nontradable sector, $\log A_{N,t}$, we can incorporate one more observation from the data. Therefore, the model is now estimated to fit five observations—three sectoral real value added data (Y_l, Y_k, Y_N) and two aggregate observations as before (C, I). Compared to the previous two-sector model, we now have three new parameters pertaining to the nontradable sector to estimate: the investment

Table A.2: Prior and posterior distribution of parameters

Parameter	Description	Prior			Posterior		
		Density	Mean	Stdev	Mode	Stdev	[5th, 95th]
ν	Preference	Beta	0.5	0.15	0.7353	0.0957	[0.6130,0.9045]
θ	Elasticity of substitution	Inverse Gamma	0.99	0.5	0.5169	0.0864	[0.4994,0.7549]
b_k	Adjustment cost in sector k	Normal	0.5	0.5	0.1141	0.0344	[0.0747,0.1913]
b_l	Adjustment cost in sector l	Normal	0.5	0.5	0.6371	0.2419	[0.1560,0.6240]
ρ_z	Persistence in z_t	Beta	0.5	0.15	0.5899	0.0791	[0.4713,0.7273]
ρ_λ	Persistence in λ_t	Beta	0.5	0.15	0.46	0.0758	[0.3709,0.5706]
σ_z	Std in shocks to z_t	Inverse Gamma	0.05	0.1	0.0135	0.0016	[0.0122,0.0165]
σ_λ	Std in shocks to λ_t	Inverse Gamma	0.05	0.1	0.028	0.0027	[0.0282,0.0386]
η_l	elasticity to agg shocks	Inverse Gamma	1	1	1.6725	0.1175	[1.5264,1.7723]

adjustment cost, b_n, the persistence parameter to nontradable productivity shocks ρ_N and the volatility of nontradable productivity shocks σ_N. The choices of the prior distribution are similar to the two-sector case.

Table A.3 presents the prior distribution as well as the estimated results. Similar to the two-sector case, ν is estimated to be 0.44, allowing for significant income effect. The elasticity of substitution between capital- and labor-intensive goods is 0.514, very close to the previous estimation. Tradable labor-intensive sector is much more responsive to the aggregate shock than the tradable capital-intensive sector, with η_l estimated to be 1.977. The tradable sector shocks are less persistent than the nontradable sectors ($\rho_z < \rho_N$), but the volatility of nontradable-specific shocks is higher ($\sigma_z < \sigma_N$).

Table A.3: Prior and posterior distribution of parameters

Parameter	Description	Prior			Posterior		
		Density	Mean	Stdev	Mode	Stdev	[5th, 95th]
ν	Preference	Beta	0.5	0.15	0.4406	0.076	[0.2790,0.5196]
θ	Elasticity of substitution	Inverse Gamma	0.99	0.5	0.5140	0.0947	[0.4106,0.5768]
b_k	Adjustment cost in sector k	Normal	0.5	0.5	0.6370	0.1916	[0.5588,1.0276]
b_l	Adjustment cost in sector l	Normal	0.5	0.5	0.8231	0.1942	[0.5236,1.4528]
b_N	Adjustment cost in sector N	Normal	0.5	0.5	1.4934	0.2597	[1.2704,1.7334]
ρ_z	Persistence in z_t	Beta	0.5	0.15	0.2201	0.0814	[0.0777,0.3837]
ρ_λ	Persistence in λ_t	Beta	0.5	0.15	0.5166	0.0698	[0.4735,0.6092]
ρ_N	Persistence in $\log A_{N,t}$	Beta	0.5	0.15	0.6272	0.0694	[0.4490,0.7055]
σ_z	Std in shocks to z_t	Inverse Gamma	0.05	0.1	0.0210	0.0052	[0.0145,0.0278]
σ_λ	Std in shocks to λ_t	Inverse Gamma	0.05	0.1	0.0246	0.003	[0.0213,0.0321]
σ_N	Std in shocks to $\log A_{N,t}$	Inverse Gamma	0.05	0.1	0.0328	0.0032	[0.0279,0.0359]
η_l	elasticity to aggregate shocks	Inverse Gamma	1	1	1.9767	0.4452	[1.6040,3.0016]

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