International Business Cycles with Multiple-Input Investment Technologies*

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Abstract

Backus, Kehoe, and Kydland (International Real Business Cycles, JPE, 100 (4), 1992) documented several discrepancies between the observed post-war business cycles of developed countries and the predictions of a two-country, complete-market model. The main discrepancy dubbed as the quantity anomaly, that cross-country consumption correlations are higher than that of output in the model as opposed to the data, has remained a central puzzle in international economics. The main thesis of this paper is that when the standard two-country model with traded and non-traded goods and complete financial markets, as in Stockman and Tesar (Tastes and Technology in a Two Country Model of the Business Cycles: Explaining International Comovements, 85 (1), AER, 1995) is extended to include capital goods sectors that utilize both traded and non-traded goods as intermediates, and when the non-traded aggregate is reclassified to include distribution and transportation services, the model produces the correct ordering of the cross-country correlations of consumption and output.

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1 Introduction

That cross-country consumption correlations substantially exceed output correlations in theoretical models, at complete variance with what is observed in the data for developed countries, has puzzled researchers in international economics for about two decades. The puzzle, first highlighted and dubbed as the "quantity anomaly" by Backus, Kehoe, and Kydland (1992), emerged from a world-economy model comprising two countries, a single consumption good, and complete financial markets. Researchers have resorted to various strategies to resolve this puzzle, including restricting asset trades and introducing non-traded goods.[1] While these strategies have been successful in partially closing the gap, the *ordering* of the correlations has stayed unchanged: the cross-country consumption correlation still exceeds that of output in the two-country model. Table 1 summarizes the relative success of past studies in this respect.

The source of the quantity anomaly in Backus et al. (1992) is easy to identify. First, financial market completeness allows countries to pool their consumption risk. Second, an efficient allocation of resources commands that labor and investment be relatively higher in the country with the higher productivity. As a result, under any sequence of country-specific productivity shocks, consumptions comove across countries, while outputs move in opposite directions.

This argument suggests that departing from the complete-market setup should be the first step towards resolving the quantity anomaly. Baxter and Crucini (1995), however, show that when shocks are trend stationary and there are substantial productivity spillovers, the model with incomplete markets is essentially indistinguishable from the model with complete markets. In that case, countries' income changes are temporary and a sole non-state contingent bond attains a high cross-country correlation of consumption. With unit root shocks, income changes are permanent so that restricting asset trade does have substantial effects on the domestic and cross-country business-cycle statistics.

[1] The anomaly has also been attacked by incorporating multiple sectors (see, for intance, Ambler et al., 2002; Kouparitsas, 1998; Huang and Liu, 2003), and multiple countries (see, for instance, Yakhin, 2004; Burstein et al., 2007).

Notwithstanding this, neither complete nor incomplete markets align the cross-country correlations of consumption and output with their empirical counterparts. Under complete asset markets, consumptions are highly positively correlated but the correlation of outputs is negative. On the other hand, restricting asset trade to a sole noncontingent bond restores the positive correlation of outputs but leads to a negative correlation of consumptions.

In a similar vein, Kollman (1996) studies a bond economy with shocks slightly more persistent than those used by Backus et al. (1992) (the autocorrelation is equal to 0.95 in the former and 0.91 in the latter) and obtains a significantly lower cross-country consumption correlation relative to other studies. Kehoe and Perri (2002) endogenize the market incompleteness by introducing 'enforcement constraints', and as Kollman (1996), they assume that productivity shocks are highly persistent, although they rule out the possibility of cross-country spillovers. With these changes, Kehoe and Perri (2002) obtain a substantial improvement in the ordering of the correlations. Finally, Heathcote and Perri (2002) completely eliminate assets trade. Yet in their model, the consumption correlation largely exceeds the output correlation.

Instead of relaxing the complete-markets assumption, Stockman and Tesar (1995) attack the puzzle by disaggregating the economy into non-traded and internationally traded sectors. To understand how this disaggregation helps, consider a positive productivity shock in the non-traded sector in one of the countries. Insofar as non-traded goods must be entirely consumed domestically, the consumption of non-traded goods increases and, due to complementarity, the consumption of traded goods rises as well. Both output and consumption rise in one country without a rise in the consumption of the other. Thus, introducing non-traded goods significantly helps in restoring the within-country consumption and output comovement. However, the model solely driven by technology shocks obtains a high (0.94) cross-country correlation between the consumptions of traded goods, and as a result, the correlation between aggregate consumptions exceeds that of the aggregate outputs. Stockman and Tesar (1995) then incorporate taste shocks by letting the relative preferences for traded consumption stochastically differ across time and countries. Although the cross-country correlation of consumption is lower with taste shocks, the quantity anomaly is still present in their model.

It bears emphasis that in all of the above referred studies except the one endowed with non-state contingent bonds and unit-root shocks, $\rho(c, c^*) > \rho(y, y^*)$, i.e., the cross-country correlation of consumption exceeds that of output. This is summarized in Table 1.

The thesis of this paper is that the two-country model of Stockman and Tesar (1995) without taste shocks can solve the quantity puzzle if it incorporates a more realistic input-output structure in the production of capital goods. More specifically, the model must recognize that in the real world, capital goods in the traded and non-traded sectors are produced using inputs of traded (both exportables and importables) and nontraded goods.

How does incorporating multiple-input capital goods technologies resolve the anomaly? First, irrespective of whether a productivity shock occurs in the traded or the non-traded sector, a temporarily high sectoral productivity raises the corresponding sectoral investment demand, which in turns boosts the demands for inputs of non-traded, exportable, and importable goods. As a result, both within country traded and non-traded output comovements, as well as cross-country aggregate output comovements, are stronger.

As for the comovement of the countries' consumptions, consider first a positive productivity shock in the traded sector. In the Stockman and Tesar's (1995) model, where final outputs and capital goods are homogeneous, in the sense that sectoral outputs can be converted one-to-one into their respective sectoral capital goods, the rise in the country's traded-sector output not only feeds the sector's increased investment demand, but it is also shared for consumption between the two countries. By complementarity, the consumption of non-traded goods also rises in both countries, so consumptions comove strongly across countries. When capital goods are produced by utilizing inputs from all sectors, the investment boost that follows a rise in the traded sector productivity raises the demand for non-traded goods as these goods are used as inputs to produce capital goods for the traded sector. As a result, relative to the model in which capital goods and final outputs are homogeneous, more of non-traded and less of traded goods are produced. Yet, it is possible that, on impact, the consumption of non-traded goods declines as more non-traded output is allocated to produce investment goods for the traded sector. Consequently, aggregate consumption rises relatively less in the model endowed with a more realistic input structure in its investment sectors. Furthermore, less traded goods production also reduces traded consumption sharing across countries. Overall, the aggregate consumption comovement across countries declines in that model.

When a positive shock occurs in the productivity of the non-traded sector, the sectoral investment demand rises. As the production of investment goods utilizes inputs from all sectors, the consumption of non-traded goods rises more in the multiple input investment model than in the homogenous good model. This aligns the domestic consumption and output movements. On the external front, traded consumption in the other country falls on impact since some of its exportables have to be used as inputs for investment in the country with the shock. Thus, the comovement of cross-country traded consumption, and therefore of aggregate consumption, is weaker.

The above results are first obtained in a version of the Stockman and Tesar's (1995) model that is extended to include multiple-input investment technologies. Despite a significant improvement, the model's cross-country consumption correlation still exceeds that of output. The paper then reclassifies sectoral output aggregates. Deviating from Stockman and Tesar (1995), distribution and transportation services are included in the non-traded instead of the traded aggregate. Consequently, the relative size of the non-traded sector increases substantially. Specifically, the ratio of non-traded to traded output, which equals 1 in the Stockman and Tesar's (1995) classification of goods, rises to 2.25 under the proposed reclassification. When the model is recalibrated to match the latter ratio, the quantity anomaly vanishes. Since non-traded goods cannot be shared across countries, by increasing the importance of the non-traded sector, the recalibration further helps in restoring the within-country output and consumption comovements. Yet, in line with the paper's main thesis, the recalibration fails to resolve the anomaly when multiple input investment technologies are removed from the model.

In recent years, researchers attempting to explain several international relative-price puzzles have paid close attention to the role of distribution services, i.e. the transportation, wholesaling, and retailing services incorporated into every unit of traded goods before it becomes available for domestic consumption. For instance, Burstein, Neves, and Rebelo (2003) explain the 'excess' real exchange rate appreciations during exchange-rate-based stabilizations plans by introducing the non-traded cost of distributing traded goods.[2] In concluding their work, Burstein et al. (2003) conjecture that distribution costs may potentially explain the quantity puzzle. The rationale is that when distribution services are part of the non-traded output, the model with distribution costs can be viewed as a model without distribution costs but with a modified utility function that has a substantially stronger complementarity between traded and non-traded goods. Then, the within-country comovement between traded and non-traded consumptions is likely to be stronger than the cross-country consumption comovement.

To test this conjecture, this paper's model also incorporates distribution services. But, unlike Burstein et al. (2003) and Corsetti and Dedola (2005) who assume that distribution services are non-traded goods, this paper follows the data at recognizing that the production of distribution services uses inputs of expotables, importables, and non-traded goods.[3]

Simulations results indicate that the correlations are rather unresponsive to the removal of distribution services. Consider for example a shock to the productivity of the traded sector. The resultant rise in the consumption of traded goods raises the demand for distribution services, or, in other words, the demand for non-traded goods. This tends to align the within country traded and non-traded consumption comovements more than the cross-country consumption comovements. Then, why does not the model with distribution services perform better? Matching actual, aggregate macroeconomic ratios requires a recalibration of the model after removing the distribution services; whereas the ratio of traded to non-traded output remains unchanged in that recalibration, a larger weight must

[2]See also Corsetti and Dedola (2005) who examine pass-through to import and consumer prices in a New-Keynesian model of international price discrimination.

[3]See Campa and Goldberg (2006) who provide a detailed break up of the inputs utilized to produce distribution services in a large set of countries.

be assigned to the non-traded consumption in total consumption. Thus, when there is a rise in the traded consumption, the demand for non-traded goods rises in a similar way in both settings of the model. Consequently, under both specifications, within and cross country consumption comovements are similar.

The remainder of the paper is organized as follows. Section 2 is an empirical section. It provides an estimate of the matrix of technical coefficients for the industries producing capital goods and distribution services in the US. The section also reports an updated version of the international business-cycle statistics including the cross-country correlations of consumption and output. The model is presented in Section 3. Two quantitative sections follow next. Section 4 studies how merely adding multiple-input capital goods to the Stockman and Tesar's (1995) model makes a significative progress at solving the quantity puzzle. The second quantitative section, Section 5, presents the calibration of this paper's model and the results of its numerical simulations including the effect of removing the distribution services. Section 6 offers some concluding remarks.

2 Empirical evidence

This section presents the empirical evidence that motivates the inclusion of the multiple-input investment technologies in the model of the next section. The first part presents an estimate, via an input-output accounting exercise, of the matrix of technical coefficients of the US production of investment goods and distribution services. The second part presents an update of the basic international business cycle statistics widely discussed in the related literature.

2.1 Investment goods and distribution services: the matrix of technical coefficients

The goal here is to bring out the shares of exportables, importables, and non-traded goods used in the production of three goods in the US: capital goods used in the production of traded goods, capital goods used in the production of non-traded goods, and distribution services. The estimates of these shares are shown in 2.

The construction of these estimates starts with the industrywide investment data reported by the Bureau of Economic Analysis (BEA). For the period 1947-2004, these data identify two types of investment, namely Equipment & Software (E&S) and Structures.[4] According to the BEA data, on average, traded sectors of the US economy spend 69% of their investment expenditures on E&S and the remaining 31% on Structures. Non-traded sectors spend 39% of their investment expenditures on E&S and the remaining 61% on Structures. Both E&S and Structures, in turn, are produced by combining inputs from the traded and non-traded sectors of the economy.

To arrive at the non-traded shares in the production of the capital goods reported in the last column of Table 2, it is necessary to ascertain the traded/non-traded component of E&S and Structures. In E&S, the BEA includes "machinery, equipment, furniture, vehicles, and computer software" all of which are traded goods according to the GDP value-added classification of this paper. In other words, the inputs of the firms producing E&S are exclusively traded goods. On the other hand, the BEA defines Structures as the "products that are usually constructed at the location where they will be used and that typically have long economic lives." Based on this definition, it is assumed that the *unknown* traded/non-traded decomposition of Structures is the same as the *known* traded/non-traded decomposition of gross output in the construction industry. Here, it helps to refer to the BEA's input-output tables for 1997 and 2004, which indicate that the value added of the construction industry is roughly equal to one-half of the value of gross output. The remaining half consists of intermediate inputs, about half of which are traded goods. This implies that the share of traded goods in the production of Structures is roughly equal to 25%.

As non-traded sectors spend 61% of their investment expenditures on Structures, and Structures contain 75% of inputs from non-traded goods, the share of non-traded inputs

[4] The corresponding tables in the BEA database are Table 3.7E, Historical-Cost Investment in Private Equipment and Software by Industry; and Table 3.7S, Historical-Cost Investment in Private Structures by Industry.

in the cost of producing capital goods for the non-traded sector equals 45.8% (= $0.61 \times 0.75 + 0.39 \times 0$)[5], as reported in the last column of Table 2; the remaining 54.2% expenditure pertains to traded inputs. Similarly, since the traded sectors spend 69% of their investment expenditures on E&S and 31% on Structures, the share of non-traded inputs in the cost of producing capital goods for the traded sector equals 23.3% (= $0.31 \times 0.75 + 0.69 \times 0$); the remaining 76.7% is spent on traded inputs.

It now remains to decompose traded inputs into exportables and importables, as has been reported in the two central columns of Table 2. To ascertain this, a reference is made to 1967-2004 BEA table of Exports and Imports of Goods and Services by Type of Product, which identifies three items as investment goods: durable goods for industrial use, capital goods, and automotive vehicles, engine, and parts. The last category, however, includes consumers' purchases of vehicles. The BEA's benchmark 1997 import matrix, which indicates that about 32.4% of automotive imports are allocated to private fixed investment, permits overcoming this shortcoming.

This BEA, export-import data can be combined with the BEA, annual, idustrywide investment data to obtain the annual (1967-2004) total import expenditures for private fixed investment. For example, in 1997, the import expenditures on durable goods for industrial use, capital goods, and automotive vehicles, engines and parts were equal to 69.2, 253.4, and 139.5 (current) billion dollars, respectively. By excluding consumer imports of automotive products, the total import expenditure for private fixed investment in that year turns out to be 367.8 billion dollars (= $69.2 + 253.4 + 139.5 \times 0.324$).

What it is not clear yet is whether these imports constitute E&S or the traded component of investment in Structures. The BEA's benchmark 1997 import matrix is utilized to unwind this issue. It informs that the total import expenditure by the construction industry is about 6% of the total import of capital goods. The remaining 94% therefore falls into E&S. These shares are now used for decomposing each year's imports into investment for E&S and Structures. Thus, in the year 1997 example, the total import expenditure on

[5] The second term withink brackets is zero because the production of E&S exclusively uses traded inputs.

E&S and Structures equals 345.7 and 22.1 billion dollars, respectively.

The question now is how to impute these imports to the investments made by the traded and non-traded final goods sectors. This is answered by following the methodology the BEA uses to compute its commodity import matrix. The BEA imputes imports of commodities to industries by using the proportions in which these industries demand domestically supplied goods. Adhering to this convention requires that the imports of E&S and imports of capital goods for Structures be imputed to the traded and non-traded sectors with the same ratios as the ones observed for their total investment on these capital goods. For the year 1997 example discussed above, 28% of the economywide investment on E&S goes to the traded sector and the remaining 72% to the non-traded sector; the respective numbers for Structures are 11% and 89%. Then the imputed traded and non-traded sector's import expenditure on investment goods becomes 99.2 ($= 345.7 \times 0.28 + 22.1 \times 0.11$) and 265.6 ($= 345.7 \times 0.72 + 22.1 \times 0.89$), respectively. Similar calculations obtain a time series (1967-2004) for total import expenditures on investment goods by the traded and non-traded sectors.

Recall that each sector's total investment on traded inputs was obtained right at the beginning of this exercise. A simple division of the import series by the total traded input series obtains an average imports to total traded input ratio of 0.44, whereas for the non-traded sector the ratio equals 0.25. Applying these ratios to the expenditure shares of traded inputs, 0.767 and 0.542 in the traded and non-traded sectoral investments respectively, directly obtains the expenditure shares on domestically produced traded goods (exportables) and on importables, as reported in Table 2.

In regard to the empirical aspects of distribution services, recent studies by Burstein et al. (2003) and Campa and Goldberg (2006) have quantified the role these services play in the delivery of traded goods to consumers. These studies measure the "distribution margin" as the value of the wholesale and retail trade component (both considered as non-traded goods) incorporated into the value of the private final consumption of traded goods.

As in Burstein et al. (2003), it is assumed below that only the following GDP sectors utilize wholesale and retail services: Agriculture, Forestry, Fishing, & Hunting, Mining, and Manufacturing. The remaining sectors mainly consist of services in which the distribution margin is assumed to be zero. These assumptions, along with yearly BEA input-output tables, allow one to obtain the estimates of the US distribution margins reported in Table 2. The table also presents distribution margins for the US and the nations that represent the second country in the model. The average distribution margin for these countries is equal to 41.6% according to estimates obtained by Burstein et al. (2003).

As for the technical requirements to produce the distribution services, Table 2 shows the estimates constructed following a strategy similar to the one used for deriving the input shares in the cost of producing capital goods, and it is based on the 1997 BEA's benchmark input-output table and the 1997 BEA's import matrix.

2.2 International business cycle statistics

This section summarizes international business-cycles statistics that will be later compared with their model-generated counterparts. Since the paper's multi-sector model is calibrated to industrywide data only available at annual frequency, the same frequency is adopted to compute the business-cycle statistics. The data cover the period 1955-2005 and the source is the OECD statistics.[6] The original time series were filtered with the Hodrick-Prescott filter with a smoothing parameter set at 6.25, as suggested by Ravn and Uhlig (2002).

Table 4 shows the within-country percentage standard deviations of output, consumption, investment, and net exports, in addition to the within-country contemporaneous correlations of consumption and investment with output. These statistics are broadly consistent with the well known international business cycle facts in industrial countries: consumption is less volatile than output while investment is around three times more volatile than output; both consumption and investment are strongly correlated with output.

As the model of the next section features a world of two symmetric countries, a good match between model and the real world suggests directing the attention to the US and the

[6]The G7 countries are Canada, France, Germany, Italy, Japan, UK, and US; and the countries under EU15 are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the UK.

European aggregate EU15 when it comes to study the cross-country correlations of consumption and output. Data available for the period 1960-2004 indicate that the correlation of their outputs is equal to 0.51, while the correlation of their consumptions is equal to 0.35; that the ratio of the latter to the former, at 0.70, is less than one is what the model of next section seeks to explain.

3 The model

Motivated by the empirical evidence presented in Section 2, this section extends the two-country, three-good, complete market model of Stockman and Tesar (1995) in two dimensions. First, as in Burstein et al. (2003), traded goods can be consumed only after combining them with distribution services. Second, distribution services and capital goods are produced with specific technologies that combine both traded and nontraded goods as inputs.

Countries, which are indexed by 1 and 2, are symmetric and each of them produces a country-specific traded good, i.e., the exportable good, and a non-traded good. The good exported (imported) by country 1 is denoted as the x-good (m-good), while the nontraded good is denoted as the n-good. The symmetry across countries permits to economize on notation by only describing country 1's problem with the only proviso that country 2 exports (imports) the m-good (x-good). When necessary, country 2's variables are referred by using asterisks.

The representative household is endowed with a unit of time and it maximizes its expected lifetime utility over consumption, c_t, and leisure, $1 - h_t$, given by

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \frac{c_t^{\gamma} (1 - h_t)^{\eta}}{\gamma} \tag{1}$$

where $\beta \in (0, 1)$ is the discount factor; $(1 - \gamma)^{-1}$ is the intertemporal elasticity of consumption substitution; and η is a parameter affecting the share of leisure in utility. Consumption represents a composite of three goods:

$$c_t = \left[\omega \ \left(c_{xt}^{\nu} c_{mt}^{1-\nu}\right)^{-\rho} + (1-\omega) \ \left(c_{nt}\right)^{-\rho}\right]^{-\frac{1}{\rho}} \tag{2}$$

where c_x, c_m, and c_n denote the consumption of exportables, importables, and non-traded goods; ω and $1-\omega$ are the weights in agents' preferences of traded and non-traded goods, and $(1+\rho)^{-1}$ is the elasticity of consumption substitution between these two goods. The traded-good composite is a Cobb-Douglas aggregator in which ν denotes the share of exportables. The specifications of the functional forms of the utility index in (1) and the consumption composite (2) follow Stockman and Tesar (1995).

Traded and non-traded goods are produced with sector-specific, Cobb-Douglas technologies that combine sector-specific capital and labor; namely k_x and h_x produce the exportable good while k_n and h_n produce the non-traded good. The labor allocations $h_x \geq 0$ and $h_n \geq 0$ are constrained to satisfy the following:

$$h_{xt} + h_{nt} \leq h_t \leq 1 \tag{3}$$

The output of traded goods is allocated between gross exports, e_x, domestic consumption, c_x, and as inputs for producing distribution services and capital goods. The output of non-traded goods, similarly, is allocated between domestic consumption, c_n, and as inputs as well. Let x_d, x_x, and x_n (respectively, n_d, n_x, and n_n) denote the amount of traded (respectively, non-traded) goods used as inputs in the production of distribution services, investment goods for the exportable sector, and investment goods for the non-traded sector. The resource constraints on the use of exportable and non-traded goods are:

$$c_{xt} + \sum_{i=d,x,n} x_{it} + e_{xt} \leq \lambda_{xt} \left(k_{xt}\right)^{\theta_x} \left(h_{xt}\right)^{1-\theta_x} \tag{4a}$$

and

$$c_{nt} + \sum_{i=d,x,n} n_{it} \leq \lambda_{nt} \left(k_{nt}\right)^{\theta_n} \left(h_{nt}\right)^{1-\theta_n} \tag{4b}$$

where λ_x and λ_n are sectoral productivity shocks and $\theta_x \in (0,1)$ and $\theta_n \in (0,1)$ are the capital-share parameters in their respective Cobb-Douglas technologies.

Distribution services and investment goods are also produced with Cobb-Douglas technologies, as follows:

$$s_{it} = \mu_i \ (x_i)^{\alpha_i} (m_i)^{\epsilon_i} (n_i)^{1-\alpha_i-\epsilon_i}, \quad i = d, x, n \tag{5}$$

Here s represents output, μ is a scale parameter, and m denotes inputs of importable goods; $\alpha \geq 0$ and $\epsilon \geq 0$ are input-share parameters, and $\alpha + \epsilon \leq 1$.

The investments undertaken in the two sectors mature in one period:

$$k_{it+1} = (1 - \delta_i) \, k_{it} + s_{it}, \quad i = x, n \tag{6}$$

where δ_i denotes the depreciation rate of capital in sector i.

As country 1's exports are country 2's imports and viceversa, the following worldwide constraint on the use of importables (exportables) must hold:

$$c_{mt} + \sum_{i=d,x,n} m_{it} \leq e^*_{mt} \tag{7}$$

where e^*_m is the export (import) of good m by country 2 (1).

Distribution services are incorporated into consumption by assuming that ψ_x (ψ_m) units of distribution services are necessary to convert a unit of exportables (importables) into a unit of *consumable* exportable (importable) goods. Thus, the production and use of distribution services satisfies the following:

$$s_{dt} \geq \psi_x c_{xt} + \psi_m c_{mt} \tag{8}$$

To complete the description of the problem, the sectoral technology shocks are assumed to evolve according to a VAR(1) process which is symmetric across countries:

$$\lambda_{t+1} = \mathbf{\Lambda}\ \lambda_t + \varepsilon_t \tag{9}$$

where $\lambda_t \equiv [\lambda_{xt}, \lambda_{nt}, \lambda^*_{mt}, \lambda^*_{nt}]$; $\mathbf{\Lambda}$ is a 4×4 matrix of autoregressive coefficients; and $\varepsilon_t \equiv [\varepsilon_{xt}, \varepsilon_{nt}, \varepsilon^*_{mt}, \varepsilon^*_{nt}]$ is a vector of i.i.d. innovations with a known covariance matrix $\mathbf{\Sigma}$.

Since complete contingent-claims markets are assumed to exist, the allocations of the decentralized world competitive equilibrium are identical to the allocations obtained by a social planner who maximizes the country-weighted sum, $\zeta\, U + (1-\zeta)\, U^*$, where $\zeta \in (0,1)$ is the weight in total welfare the planner gives to country 1. The constraints of the planner's maximization problem are equations (2) to (8) for country 1, a similar set of equations for country 2, and the process for the productivity shocks (9).

It is worth noting that the foregoing model nests the Stockman and Tesar's model by (a) assuming that each sector's capital goods be produced by using exclusively its own final good, which amounts to setting $\alpha_x = \epsilon_n = 1$ in (5); (b) eliminating the distribution services by setting $s_{dt} = \psi_x = \psi_m = 0$ in (8); and (c) adding an exogenous, constant growth rate of labor-augmenting productivity, which requires re-expressing the model to induce stationarity. Note that (a) and (b) also imply setting $x_i = n_i = 0$, $i = d, x, n$, in equations (4).

4 The Stockman and Tesar's model with multiple-input investment technologies

This section shows that just adding a more realistic investment sector to the Stockman and Tesar's (1995) three-goods version of the two-country model makes substantial progress towards resolving the quantity anomaly. Their version of the model without taste shocks is augmented to incorporate the matrix of technical coefficients of investment-goods discussed in Section 2. Except for this modification, this section's results are obtained by retaining Stockman and Tesar's productivity shocks, as well as the values they assign to the technology and preference parameters. Table 5 summarizes these values and Table 6 presents the shocks' process. The solution technique used throughout is linear-quadratic approximation and all business-cycle statistics are computed from 300 simulations of 300 periods each, after disregarding the dynamics of the first 200 periods of each simulation.

The existence of traded and nontraded sectors requires using their relative prices to compute economywide aggregates. However, the choice of the price system has not been uniform in the literature. Neither has been the decision to whether or not to filter the model-generated time series. These two issues are discussed first.

Panel (a) of Table 7 displays the results of simulating the Stockman and Tesar's (1995) model without taste shocks, which correspond to the results they report in Table 6 of their paper. The economywide aggregates are computed by using equilibrium (or state-contingent) prices for adding up sectoral components. The reported statistics therefore reflect both the price and quantity effects induced by the sectoral productivity shocks in the two countries. Furthermore, as in Stockman and Tesar (1995), none of the simulated time series has been filtered.

4.1 Filtering model time series

To make consistent comparisons between model and data moment statistics, however, the same filtering technique used for the data, should be used for the model-generated time series (see, for instance, Baxter and King, 1999). Column (b) of Table 7 shows how filtering the model time series alters the results reported in column (a).[7] Overall, the results shown in Panels (a) and (b) of Table 7 indicate that filtering the simulated time series substantially changes the business-cycle statistics. On average, the standard deviations fall by 44 percent, with reductions ranging from 23 percent in hours to 80 percent in the real exchange rate. As for the cross-country correlations, filtering worsens the quantity puzzle: the cross-country correlation of output falls by 0.10 without producing a significant change in the cross-country correlation of consumption.

[7]The smoothing parameter of the H-P filter was set equal to 6.25, the value used at obtaining the empirical business-cycle statistics reported in Table 4.

4.2 Aggregation with constant and current prices

It bears emphasis that the business cycle statistics commonly computed on *actual* macroeconomic aggregates are based on either data at constant prices or volume indices. Aggregate price deflators combine price changes in all sectors that are duly weighted by their respective sizes. In other words, to isolate quantity effects, data at constant prices or volume indices not only correct for inflationary changes but also correct for the relative price changes across sectors. A consistent treatment of model and data, therefore, calls for eliminating the relative price effects from the model-generated time-series as well. By construction, a one-sector model like the one in Backus et al. (1992) fulfils this criterion.

Results in columns (a) and (b) of Table 7, however, use *current or equilibrium* relative prices to aggregate sectoral components, combining quantity and price effects. To focus solely on quantities, as in the data, columns (c) and (d) of that table report Stockman and Tesar's model statistics of aggregates that are measured by using *constant* relative prices. Comparing the results in columns (b) and (d) reveals that switching from current to constant relative prices hardly alters the relative (to GDP) volatilities of the macroeconomic aggregates. However, the switch does widen the wedge between model and data: the ratio $\rho(c, c^*)/\rho(y, y^*)$ rises from 1.39 to 1.63. Clearly, the dynamics of relative prices appear to play a substantial role for the quantity puzzle.

Figure 1 helps to see why. Its Panel (a) (respectively, b) displays the effects of a positive productivity shock in country 1 to the traded (respectively, non-traded) goods sector. The impulse responses under constant prices, in dashed lines, pin down the dynamics of quantities; solid lines show the responses when aggregates are measured at time-variant equilibrium prices. Darker (lighter) lines are used to identify the responses in country 1 (2).

The dashed lines show that following the traded sector shock, both countries raise their *quantities* consumed of traded goods, as these goods are shared across countries. By consumption complementarity, the consumption of non-traded goods rises on impact on both countries as well. Overall, the two countries experience a hike in their consumptions.

The *quantity* produced of exportables rises in country 1, and as labor is reallocated toward this sector, the production of non-traded goods falls.[8]

When the same responses are computed using current prices, a different picture emerges. As the relative price of non-traded goods rises in both countries, non-traded GDP rises in both countries because the price effect dominates the quantity effect. This, in part, explains why the cross-country correlations of GDP and consumption rise from 0.38 and 0.62, when aggregates are computed at constant prices, to 0.62 and 0.86 when they are computed at current prices.

Panel (b) of Figure 1, which addresses the effect of a productivity shock in the nontraded sector of country 1, shows that switching from constant to current prices reduces the cross-country comovement of GDP while it raises the comovement of consumption. The price effect becomes evident in the consumption of non-traded goods: although the quantity of non-traded goods consumed rises significantly in country 1, that rise is however shown as a fall when the current price of non-traded goods is used for the consumption valuation.

In sum, measuring consumption and output by using current prices to add up sectoral aggregates overly aligns cross-country output and consumption comovements relative to the comovement of their real quantities.

4.3 Multiple-input investment technologies

This section shows how incorporating the investment-input structure observed in the US economy changes the cross country correlations in the Stockman and Tesar's model. In terms of Section 3's model, (a) the part of the sectoral outputs allocated to produce distribution services should be set equal to zero in equations (4), i.e., $\psi_x = \psi_m = 0 \Rightarrow x_d = n_d = 0$, and (b) the multiple inputs technologies consistent with the data reported in Table 2 must be included. All other parameter values are still taken from Stockman and Tesar's model (see Table 5).

In Stockman and Tesar's calibration, the ratio of traded to non-traded output equals 1,

[8] As country 1's exportable good is the *numeraire*, the exportable GDP at constant and current prices are identical.

and both traded and non-traded consumptions are roughly 70% of their respective sectoral outputs; the imports-to-GDP ratio is about 18%. With multiple investments inputs, total investment demand for non-traded goods falls while that of traded goods rises. Consequently, the consumption of non-traded goods rises to 80% of non-traded output, while the consumption of traded goods declines to about 60% of exportable output. Since imports are now required for producing investment goods, the import-to-GDP ratio rises to 23%.[9]

The quantitative effects of introducing multiple-input investments can be seen by comparing columns (d) and (f) of Table 7. Under multiple-input investment technologies, the volatilities of the first four variables fall while that of the last four rise. The most significant increases are in the terms of trade and the real exchange rate, whose volatilities more than double. More important for the thesis of this paper is that the ratio of the cross country correlations $\rho(c, c^*)/\rho(y, y^*)$ depicts a sharp drop from 1.63 to 1.07. The decline in this ratio is jointly explained by the cross-country correlation of consumption that falls from 0.62 to 0.47 and the cross-country correlation of output that rises from 0.38 to 0.44.

Appealing to impulse responses again helps top understand the results. By comparing the two lighter colored lines in Figure 2, it can be seen that, compared to what occurs in country 1, introducing the new investment technologies does not change the responses of country 2's variables significantly. This hints that the resolution of the quantity puzzle lies more in the country 1's than in country 2's responses to both shocks.

Panel (a) of the figure shows the response to a positive productivity shock in country 1's traded sector. The most striking differences arise in the production and consumption of non-traded goods. While non-traded output of country 1 falls when the sectors' own final goods can be used directly as capital in the next period (as it happens in Stockman and Tesar's model), that output rises when investment requires multiple inputs. If the traded sector investment uses only traded final goods, labor moves from the non-traded to the traded sector and the output of non-traded goods falls. Instead, with the multiple-input

[9] In another version of the model whose simulation results are not reported, the investment technologies utilize only exportable and non-traded goods as inputs and the import-to-GDP ratio falls to 14%. None of the results to be reported next changes significantly in the alternative setting.

investment technologies, the demands for exportable, importable, and non-traded goods rise due to an investment boost in the exportable sector. As a result, country 1's non-traded output and county 2's exportable output rise relative to Stockman and Tesar's version of the model. Overall, the cross country comovement of aggregate outputs rises under multiple-input investment technologies, thus partially explaining why the cross-country output correlation rises from 0.38 to 0.44 with the proposed investiment specification.

The non-traded consumption responses are however different. In country 1, a higher exportable sector investment demand raises the relative price of non-traded goods leading to a decrease in its consumption on impact. Consumption of non-traded goods in country 2 is however unaltered on impact. This partially explains why the cross-country correlation of non-traded consumption falls from 0.35 to 0.24 when the Stockman and Tesar's model is augmented to include multiple-input investment technologies.

Consider now the positive productivity shock in the non-traded sector of country 1 (see Panel (b) of Figure 2). The resulting hike in the sector's investment raises the demand for exportables and importables when investment technologies use multiple inputs. The production of exportables in both countries rise in contrast to Stockman and Tesar's model in which the exportable output falls in both countries. As a result, traded sector outputs appear to be more aligned under multiple input investment technologies. On the other hand, the outputs of non-traded goods is relatively lower in both countries under multiple-input investment technologies but their comovements are roughly alike. Thus, under both traded and non-traded shocks, countries' traded outputs are more aligned, which explains why the cross-country correlation of traded output rises from 0.39 to 0.59.

The same Panel (b) of the figure shows that while the consumption of traded goods rises on impact in both countries in the Stockman and Tesar's model, with multiple input investment technologies, the higher demand for exportables to be used in producing capital goods leads to a lesser rise in traded consumption. Indeed, in country 2 the traded consumption falls. Also, in country 1, when the non-traded sector uses other sectors' inputs to produce capital, a higher amount is left for nontraded consumption. Thus, country 1's rise and then decline of non-traded consumption is steeper under the multiple-input investment version, whereas country 2's non-traded consumption hardly changes. As a result, the cross-country comovements of both traded and non-traded consumption are diminished when investments utilize multiple inputs, which partially explains why the cross-country consumption correlation falls from 0.62 to 0.47 in this version of the model.

5 Quantitative results from the full model

Section 4 shows that augmenting the Stockman and Tesar's (1995) model to introduce the empirical input structure in the production of capital goods brings the relative cross-country correlations of output and consumption closer to that observed in the data. For expositional reasons, the results in that section were obtained by modifying Stockman and Tesar's calibration as little as possible, albeit at the expense of some potential misalignments between the model and the empirical macroeconomic ratios. This section shows that the data-model matching of the cross-country correlations improves further with a more careful calibration of the model. In particular, it is shown that the quantity puzzle stated in the Introduction vanishes once the full model of Section 3 is calibrated carefully.

Mostly due to data limitations (see footnote 11 of their paper), Stockman and Tesar (1995) classify retail and wholesale services, transportation services, and services of restaurants and hotels as traded goods, along with agriculture, mining, and manufacturing. Consequently, the output of non-traded goods accounts for about half of the total output in their calibration. A 60-industry database maintained by Groningen Growth Development Center (GGDC) now provides the value-added of each of the above-mentioned services separately, which facilitates their inclusion in the non-traded sector.[10] It bears emphasis that over the period 1979-2004, these services account for about 15% of GDP, not only in the US but also in the European aggregate EU15, and that the 15%-share has remained fairly stable over time. Thus, while Stockman and Tesar (1995) find that total output is approximately evenly split between traded and non traded, a more detailed reclassification

[10] The data are available at www.ggdc.net.

of the goods in the data shows that non-traded is about twice as large as traded output.

On the other hand, the model of Section 3 incorporates the evidence shown in Table 3, which indicates that about 3 units of non-traded goods have to be added to every 4 units of traded goods before the latter become consumable. Burstein et al. (2003) conjecture that the implied increase in complementarity between traded and non-traded goods within the household's consumption is likely to affect the cross-country quantity comovements. It will be shown that this seems to not be the case in this paper's model.

5.1 Calibration

The full model is calibrated to the US data, which in the case of value-added across sectors, are roughly consistent with the data of the European aggregates EU15 and EU5 (France, Germany, Italy, Netherlands, and UK) and of a G-5 group of countries (Canada, France, Germany, Italy, and U.K.). The sources of the data are the BEA, the BLS, and the OECD and GGDC statistics. All parameter values are summarized in Table 5.

The model matches the average ratio of value-added in the non-traded sector to that in the traded sector at 2.25 (BEA, 1947:2005, GDP value-added by sector). Labor compensation in the US equals 64% (62%) of the value added in the traded (non-traded) sector (GGDC, 1979-2003); thus, $\theta_x = 0.36$ and $\theta_n = 0.38$. Consistent with related studies, β is set equal to 0.96. It is assumed that households allocate 30% of their time to market activities, and that labor is perfectly mobile across sectors. Then, given the values of the sectoral outputs, those of θ_x and θ_n, the labor constraint $h = h_x + h_n$, and the equality of wages across sectors, the steady-state values of the following can be obtained: sectoral labors, h_x and h_n; sectoral capital stocks, k_x and k_n; and the final-goods technology parameters, λ_x and λ_n.

The BLS reports an average depreciation rate of 12% for Equipment & Software and 5% for Structures. It also reports that the capital stock is equally divided between E&S and Structures in the farm and manufacturing sectors (traded sectors), while the respective fractions in the non-farm, non-manufacturing sectors (non-traded sectors) are 30% and

70%. Accordingly, the depreciation rates in the traded and non-traded sectors are set to $\delta_x = 0.5 \times (0.12 + 0.05) = 0.085$ and $\delta_n = 0.30 \times 0.12 + 0.7 \times 0.05 = 0.071$, respectively.

The values of δ_x, δ_n, k_x and k_n determine the output of the industries that produce capital goods, s_x and s_n. The share parameters of the respective Cobb-Douglas technologies are set to match the ones reported in Table 2. The values of the input shares, along with those of the inputs and outputs of the capital-goods industries obtain the values of the scale parameters μ_x and μ_n.

Following the evidence presented in Section 2, the distribution margin is set to 41.6%, and consistent with the US data, the GDP share of *exports of goods* is 12% (BEA 1951: 2004). Then, given the value of the distribution margin, the share of input usage in the distribution sector from Table 3, and the goods-markets clearing conditions for the three final goods, it is possible to obtain the value of the scale parameter of the distribution technology and the value of consumption allocations for the three goods.

As for the preference parameters, following Stockman and Tesar (1995), the elasticity of substitution between traded (composite) and non-traded consumption is set to 0.44 and the intertemporal elasticity of substitution is set to 0.5. Then, the planner's first order conditions for labor, consumption of non-traded goods, and consumption of imported goods give the value of the following: the labor share in the utility function, η; the share of non-traded consumption within the consumption aggregate, ω; and the share of imports within the traded composite, $1 - \nu$.

An estimation of the VAR(1) process for $\lambda_t \equiv [\lambda_{xt}, \lambda_{nt}, \lambda^*_{mt}, \lambda^*_{nt}]$ is obtained by applying restricted OLS to time-series of sectoral Solow residuals for US and an aggregate of the following countries: Canada, France, Germany, Italy, and United Kingdom. The estimated shock process is shown in panel (b) of Table 6.

5.2 Quantitative results

Table 8 summarizes the results of this section's exercises. Column (a) repeats information already presented in Table 7 and columns (b) to (e) display the results obtained with this paper's full model.

With the Stockman and Tesar's (1995) estimated shock process, compared to the extended version of their model (see column (a)), the full model (see column (b)) delivers lower volatility of output and hours and higher volatility of investment, the trade balance, and the terms of trade. The volatility of consumption, capital, and the real exchange rate, however, are similar across models. The most important result relates to the cross-country correlations: the full model of this paper with Stockman and Tesar's shocks obtains a cross-country correlation of consumption (at 0.23) lower than the cross-country correlation of output (at 0.29). The ratio of the two correlations, at 0.79, is very similar to the 0.70 ratio reported at the end of Section 2.

As discussed before, the classification of goods between traded and non traded in this paper differs from Stockman and Tesar's classification. A fair objection therefore may be raised towards the use of Stockman and Tesar shocks for evaluating this paper's model. In this light, columns (c) and (e) present results with the shocks estimated for this paper. The model now delivers business cycle statistics that display, on average, approximately one-half of the standard deviations obtained with the Stockman and Tesar's shocks (compare columns (b) and (c) for instance). However, the relative (to GDP) standard deviations are roughly similar to those obtained with Stockman and Tesar's shocks. Essentially, if the covariance matrix of the shocks is rescaled to match the output volatility, the rest of the volatilities will also roughly match those obtained with Stockman and Tesar's (1995) shocks.[11] Still, the upshot is the resolution of the quantity puzzle: the cross-country correlation of consumption at 0.72 is lower than that of output at 0.85. The ratio $\rho(c, c^*)/\rho(y, y^*)$ equals 0.85.

Remarkably, when the sectoral investment technologies are assumed to utilize their own goods only, the results shown in column (d) indicate that the puzzle stays unresolved: both output and consumption correlations equal 0.83.[12] Yet, their ordering, with

[11] As the solution algorithm of this paper, linear-quadratic approximation, delivers allocations that display certainty equivalence, it is worth noting that rescalling the variances of the shocks does not alter the relative (to GDP) volatilities of the model nor their correlations.

[12] The model setting behind results in column (e) are: $\alpha_x = \epsilon_n = 1$.

$\rho(c, c^*)/\rho(y, y^*) = 1$, is closer to the data relative to other studies (see Table 1).

Finally, the results in column (e), which are derived after removing the distribution services, serve to illustrate that these services are not essential for this paper's results: i.e., the model statistics in columns (d) and (e) are hardly different from each other. The irrelevance of the distribution services is surprising, because one would expect that their inclusion in the model implicitly increases the complementarity between traded and non-traded goods, and therefore it will restore the within country and weaken the cross-country comovements further. The intuition why this is not the case is as follows. When distribution services are excluded, a careful model calibration that maintains the sectoral output ratios requires replacing distribution services with consumption of non-traded goods and giving non-traded goods a larger weight in utility. Given that the model already assumes a low substitutability between traded and non-traded consumption (with the elasticity of substitution at 0.44), a larger relative weight on non-traded consumption helps to restore the ordering of cross-country correlations as strongly as distribution services would do.

6 Concluding Remarks

The "quantity anomaly" highlights that the cross-country correlations of consumption exceeds those of output – the opposite to what is observed in the data – in a standard, two-country model of business cycles with complete financial markets. Researchers attempting to explain the anomaly have found that neither assuming asset market restrictions nor incorporating other elements like nontraded goods or taste shocks is enough to overcome the anomaly.

This paper has developed a version of the two-country, complete markets model that does align data and model at obtaining a cross-country correlation of consumption lower that the cross-country correlation of output. As in Stockman and Tesar (1995), the model of this paper disaggregates the economy into traded and non-traded sectors, and the traded sector, into exportables and importables. This disaggregation of the economy, by itself, is shown not to be enough to solve the quantitative anomaly. What solves the anomaly is relaxing the assumption that each sector's output and investment goods are the same good. More specifically, aligning model and data requires endowing the model with an additional dose of realism by recognizing that capital goods are produced using inputs of exportable, importable, and nontraded goods, so that any changes in the production possibilities of one sector directly impacts those of the others.

The finding that incorporating multiple-input investment technologies in the production of capital goods solves the quantity anomaly is robust to several specifications of the model, its parameter values, and its sources of dynamics. Among these, the paper has shown that incorporating distribution services in the model has no bearing whatsoever on the resolution of the quantity anomaly.

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Table 1: Cross-country Correlations of Consumption and Output in the Data, and in the Present and Previous Studies

Study / Data	$\rho(c, c^*)$ (a)	$\rho(y, y^*)$ (b)	Ratio (c)=(a)/(b)
U.S. Data[§] (maximum)	0.90	0.80	0.95
U.S. Data (minimum)	0.50	0.30	0.60
Bakus, Kehoe, and Kyndland (1992)	0.88	-0.18	-4.89
Baxter and Crucini (1995)[†]	0.92	0.06	15.33
Baxter and Crucini (1995)[‡]	-0.28	0.54	-0.52
Heathcote and Perri (2002)	0.85	0.24	3.54
Kehoe and Perri (2002)	0.29	0.25	1.16
Kollman (1996)	0.38	0.10	3.80
Stockman and Tesar (1995)	0.68	0.63	1.08
Present Study	*0.72*	*0.85*	*0.85*

Notes: §: U.S. data corresponds to the average of the correlations between U.S. and the countries in Table 4 for the period 1955-2005. $\rho(x, x^*)$ denotes the cross-country correlation of variable x. Figures in the table are the best predictions of the corresponding models. †: incomplete-markets model with trend-stationary shocks; ‡: incomplete-markets model with unit-root shocks without without cross-country spillovers.

Table 2: Shares of Inputs in the Total Input Costs of Producing Capital Goods and Distribution Services (in percentages)

Sector	Input		
	Traded		Nontraded
	Exportables	Importables	
Capital Goods			
Traded	42.7	33.7	23.3
Non-traded	40.6	13.5	45.8
Distribution Services	15.0	2.4	82.6

Source: Bureau of Economic Analysis (BEA). Historical-Cost Investment in Private Equipment and Software by Industry (1947-2004); Historical-Cost Investment in Private Structures by Industry (1947-2004); Input-Output Tables 1997 and 2004; Import matrix 1997; Exports and Imports of Goods and Services by Type of Product (1967-2004).

Table 3: Distribution Margins in the Present and Previous (in percentages) Studies

	Canada	France	Germany	Italy	U.K.	U.S.
Burstein, Neves, & Rebelo (2002)	41.2	35.0	41.5	43.3	45.4	43.4
Campa & Goldberg (2005)	-	33.5	40.3	42.0	48.7	42.8
	1987	1992	1997	2002	2005	
Present Study for the U.S.	39.8	42.0	45.1	46.0	46.2	

Source: The BEA's Input-Output Tables for 1987, 1992, 1997, 2002, and 2005 have been utilized for constructing the time series on the U.S. distribution margin. The distribution margin is the value of the wholesale and retail trade component incorporated into the value of the private final consumption of traded goods.

Table 4: Within-Country Business Cycles Statistics: 1955-2005, Annual Data

Country	Standard Deviaton (%)				Autocorr.	Correlation with GDP		
	y	c	x	nx/y	y	c	x	nx/y
EU	0.80	0.70	2.03	0.30	0.30	0.85	0.89	-0.53
US	1.36	1.06	3.66	0.31	0.23	0.90	0.95	-0.40
UK	1.24	1.35	2.96	0.42	0.32	0.79	0.72	-0.42
Japan	1.44	1.09	3.61	0.51	0.32	0.84	0.95	-0.46
Italy	0.69	1.01	2.57	0.75	0.40	0.69	0.86	-0.29
Germany	0.66	0.64	2.24	0.54	0.04	0.75	0.76	-0.13
France	0.71	0.64	2.45	0.41	0.42	0.81	0.84	-0.25
Canada	1.20	0.99	3.28	0.76	0.31	0.87	0.69	-0.20

Note: Business cycles statistics computed using HP-filtered annual OECD data with the filter parameter $\lambda = 6.25$. Notation is as follows: y: GDP; c: consumption; x: investment; nx/y: ratio of net exports to GDP. Consumption corresponds to private final consumption. Length of the series varies across countries: Canada: 1961-2005; France: 1978-2005; Germany: 1991-2005; Italy: 1980-2004; Japan: 1955-1999; UK and US: 1955-2005; EU: 1960-2004.

Table 5: Parameter Values: Stockman & Tesar's (1995) Model and Present Study

Notation	Explanation	Parameter Value		
		Stockman & Tesar		This Study
		capital-goods firms excluded	capital-goods firms included	
		Final goods technology		
(θ_x, θ_n)	Capital shares in output	(0.39, 0.44)	(0.39, 0.44)	(0.36, 0.38)
(λ_x, λ_n)	Productivity shocks	(2.87, 1.75)	(2.87, 1.28)	(3.24, 2.67)
		Capital goods technology		
(δ_x, δ_n)	Depreciation rates	(0.10, 0.10)	(0.10, 0.10)	(0.01, 0.06)
(α_x, α_n)	Share of exportables	(1,0)	(0.43, 0.41)	(0.43, 0.41)
(ϵ_x, ϵ_n)	Share of importables	(0,1)	(0.34, 0.13)	(0.34, 0.13)
(μ_x, μ_n)	Scale parameters	(1,1)	(3.84, 1.44)	(2.92, 2.70)
		Distribution services		
α_d	Share of exportables	-	-	0.15
ϵ_d	Share of importables	-	-	0.024
μ_d	Scale parameter	-	-	1.71
(ψ_x, ψ_m)	Requirement of distrib. services†	(-, -)	(-, -)	(0.71, 0.71)
		Preferences		
ν	Share of exportables‡	0.5	0.5	0.517
ω	Weight on traded composite	0.5	0.5	0.038
$(1+\rho)^{-1}$	Elasticity of substitution§	0.44	0.44	0.44
η	Labor share parameter	-3.39	-3.39	-1.91
γ	CES utility parameter	-1	-1	-1

Notes: †: requirements per unit of exportable and importable goods consumed. ‡: share in the consumption of traded goods. §: between traded and non-traded goods.

Table 6: VAR Estimations of the Productivity Shocks in the Two-Country Model

(a) Stockman and Tesar's (1995) Estimation

$$\hat{\Lambda} = \begin{pmatrix} 0.154 & 0.040 & -0.199 & 0.262 \\ -0.150 & 0.632 & -0.110 & 0.125 \\ -0.199 & 0.262 & 0.154 & 0.040 \\ -0.110 & 0.125 & -0.015 & 0.632 \end{pmatrix} \qquad \hat{\Sigma} = 0.001 \times \begin{pmatrix} 0.362 & 0.123 & 0.121 & 0.051 \\ 0.123 & 0.199 & 0.051 & 0.027 \\ 0.121 & 0.051 & 0.362 & 0.123 \\ 0.005 & 0.027 & 0.123 & 0.199 \end{pmatrix}$$

(b) Estimation in the Present Study

$$\hat{\Lambda} = \begin{pmatrix} 0.162 & 0.085 & -0.043 & -0.002 \\ -0.432 & -0.014 & -0.775 & -0.113 \\ -0.043 & -0.002 & 0.162 & 0.085 \\ -0.775 & -0.113 & -0.432 & -0.014 \end{pmatrix} \qquad \hat{\Sigma} = 0.0001 \times \begin{pmatrix} 0.785 & 0.037 & 0.157 & 0.028 \\ 0.037 & 0.061 & 0.007 & -0.003 \\ 0.157 & 0.007 & 0.467 & 0.060 \\ 0.028 & -0.003 & 0.060 & 0.073 \end{pmatrix}$$

Notes: In Stockman and Tesar (1995), the shocks process was estimated with 1970-1984 data and in the present study with 1955-2005 data.

Table 7: Business Cycle Statistics in the Stockman and Tesar's (1995) Model: The Role of the Price System and the Capital-Goods Firms

Variable	Stockman & Tesar				Stockman & Tesar with capital-good firms	
	Current Prices		Constant Prices		Constant Prices	
	non-filtered (a)	filtered (b)	non-filtered (c)	filtered (d)	non-filtered (e)	filtered (f)
			Standard Deviations†			
Output	2.53	1.64	2.57	1.72	2.31	1.47
Consumption	1.60	0.73	1.24	0.51	1.26	0.50
Investment	5.33	3.95	5.95	4.56	5.41	4.06
Hours	1.05	0.81	1.05	0.81	0.96	0.74
Capital	2.01	0.40	2.01	0.40	1.77	0.42
TB	0.09	0.07	0.39	0.10	0.52	0.37
TOT	1.84	0.61	1.84	0.61	2.10	1.39
RER	2.07	0.66	2.07	0.66	2.25	1.60
			International Correlations			
Aggregate						
Output	0.72	0.62	0.40	0.38	0.49	0.44
Consumption	0.87	0.86	0.78	0.62	0.65	0.47
Investment	0.43	0.40	0.34	0.33	0.32	0.28
Hours	0.46	0.40	0.41	0.40	0.71	0.72
Capital	0.48	0.24	0.48	0.24	0.57	0.20
Traded Sector						
Output	0.62	0.55	0.32	0.39	0.58	0.59
Consumption	0.93	0.81	0.90	0.73	0.94	0.87
Investment	0.38	0.40	0.30	0.35	0.32	0.72
Nontraded Sector						
Output	0.57	0.39	0.3	0.06	0.27	0.02
Consumption	0.66	0.84	0.44	0.35	0.43	0.24
Investment	0.23	0.30	0.17	-0.02	-0.12	-0.46

Notes: †: percentage deviations with respect to the means. The numerical results correspond to average statistics of the 300 simulations conducted after solving the models with a linear-quadratic approximation algorithm. The length of the simulations is 300 periods but only the last 100 periods were considered so as to avoid initial-period problems. Columns (a) and (b) show the results corresponding to Stockman and Tesar's (1995) model, without and with HP filtering of the simulation results; columns (c) and (d) show statistics of the same model as in columns (a) and (b) but using time-and-state invariant prices instead of equilibrium (state-contingent) prices to compute macroeconomic aggregates; statistics in columns (e) and (f) correspond to an extension of Stockman and Tesar's model in which capital is not sector specific but produced by a different sector of the economy that combines nontraded, importable, and exportable goods.

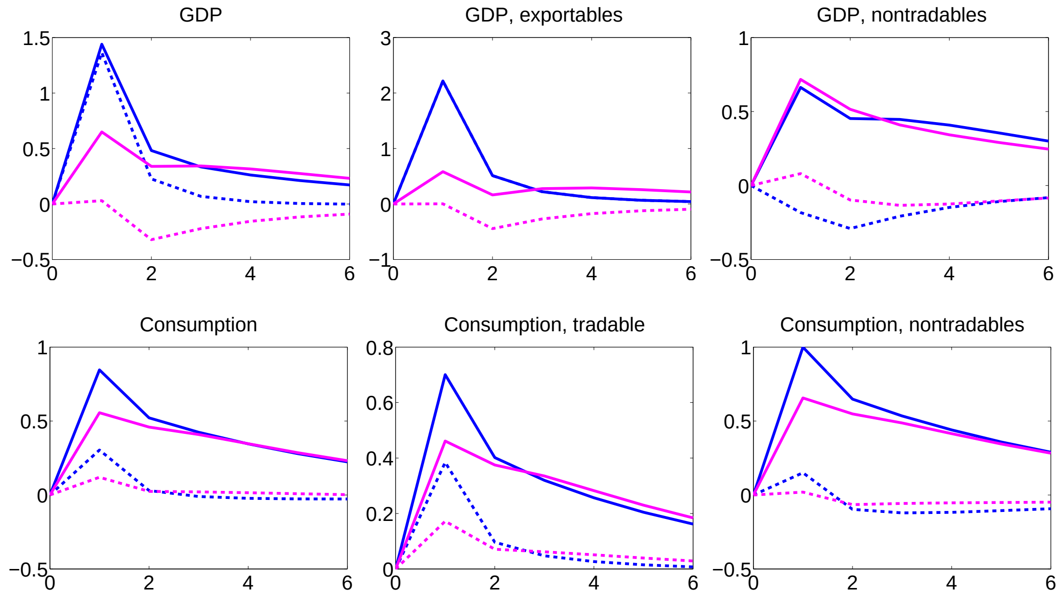
Table 8: Business-Cycle Statistics in the Model with Multiple-Input Investment Technologies

	S&T model	Present Study			
	with Capital-Goods Firms	Baseline		Without Capital-Goods Firms	Without Distrib. Services
	S&T Shocks (a)	S&T Shocks (b)	O&S Shocks (c)	O&S Shocks (d)	O&S Shocks (e)
		Standard Deviations			
Ouput	1.47	1.40	0.76	0.74	0.76
Consumption	0.50	0.52	0.23	0.19	0.23
Investment	4.06	5.50	2.58	2.56	2.57
Hours	0.74	0.67	0.38	0.39	0.38
Capital	0.42	0.32	0.12	0.12	0.12
TB	0.37	0.36	0.12	0.01	0.13
TOT	1.39	1.29	0.69	0.31	0.64
RER	1.60	1.26	0.66	0.21	0.83
		International Correlations			
Output	0.44	0.29	0.85	0.83	0.84
Consumption	0.47	0.23	0.72	0.83	0.74
Investment	0.28	-0.06	0.70	0.83	0.69
Hours	0.72	0.42	0.89	0.88	0.89
Capital	0.20	-0.07	0.48	0.70	0.47

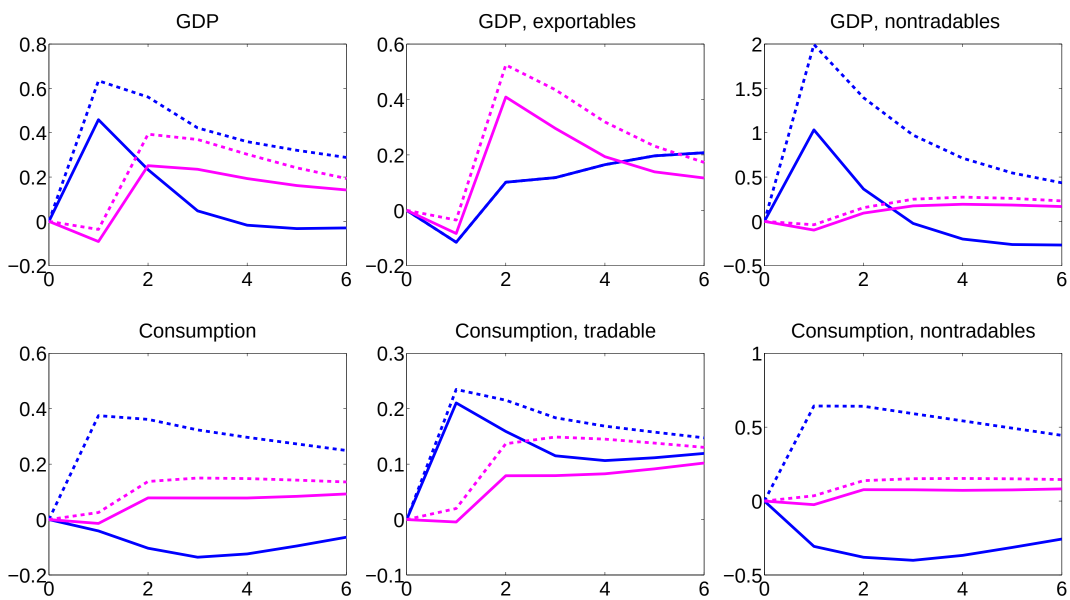
Notes: S&T refers to Stockman and Tesar (1995) and O&S to the shocks estimated in the present study.

Figure 1: Impulse Response Functions in Stockman and Tesar's Model: Constant Versus Equilibrium Prices

(a) Shock to the Productivity of Exportable Goods



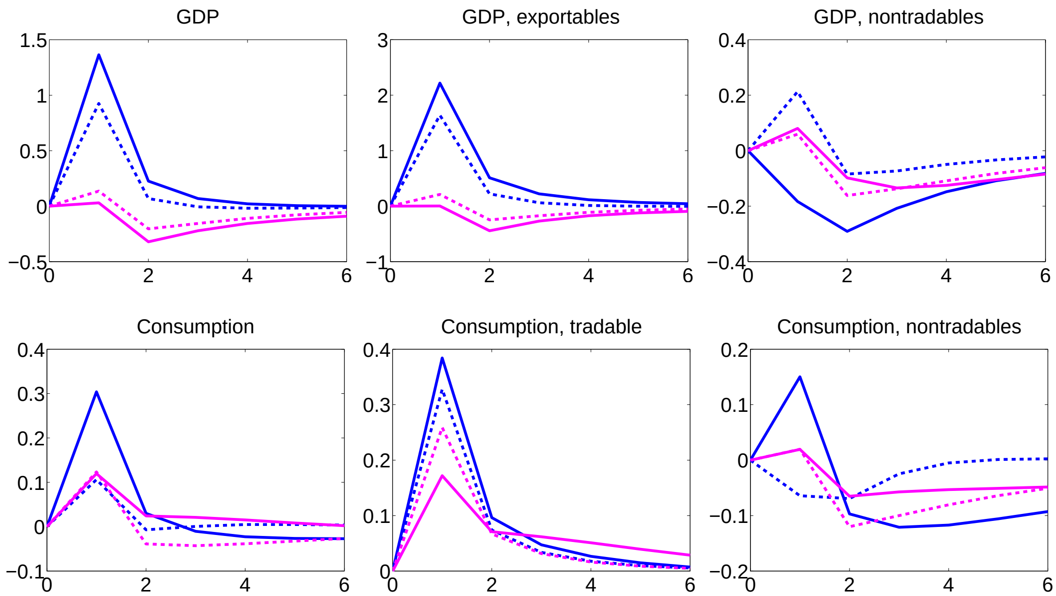
(b) Shock to the Productivity of Nontraded Goods



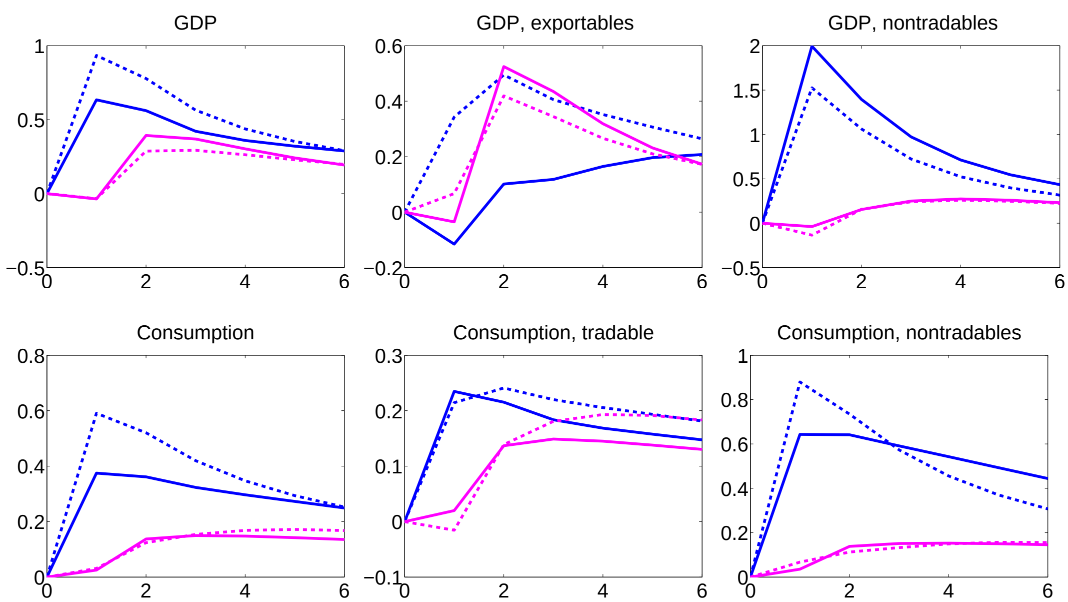
Notes: Darker (blue when colors are available) lines are used for country 1 and lighter (magenta) lines are used for country 2. For each country, solid (dashed) lines are used for the impulse-response functions computed using state-dependent (state-invariant) prices to express all variables in terms of exportable goods. State variant prices are the equilibrium prices of the model and state-invariant prices are the prices in the deterministic steady state of the model.

Figure 2: Impulse Response Functions in Stockman and Tesar's Model with and without Own Capital Goods Firms

(a) Shock to the Productivity of Exportable Goods



(b) Shock to the Productivity of Nontraded Goods



Notes: Darker (blue when colors are available) lines are used for country 1 and lighter (magenta) lines are used for country 2. For each country, solid (dashed) lines are used for impulse response functions of the model that excludes (includes) the multiple-input technologies in the production of capital goods.