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TRADE ELASTICITY AND VERTICAL SPECIALISATION

by Ines Buono* and Filippo Vergara Caffarelli*

Abstract

This paper shows that vertical specialisation can increase the elasticity of trade to income, hence explaining dramatic events such as the great trade collapse. We argue that a change in the extent of vertical specialisation affects the elasticity of trade to income, while a mere change in global production levels for a given extent of vertical specialisation does not. In the model we show that only large demand shocks induce firms to vary the extent of vertical specialisation. Using panel data starting from the late 1990s that include the 2008-09 global crisis, we consistently find that the correlation between trade elasticity and vertical specialisation increases precisely in years of large demand shocks, such as the ICT euphoria and the great trade collapse.

JEL Classification: F10, F12, L23.
Keywords: vertical specialisation, trade elasticity, global crisis, trade collapse.

Contents

* Bank of Italy, Economic Research and International Relations.

1 Introduction[1]

The sharp fall of international trade was one of the striking features of the global financial crisis of 2008-09. In the first quarter of 2009 the value of total merchandise trade of OECD countries with the rest of the world decreased by more than 17% on the corresponding period. At the same time economic activity significantly contracted, although not as much as trade: GDP in OECD countries fell by 4.7% (see figure 1).[2] These values imply an elasticity of trade to income higher than 3. Irwin (2002) estimates the historical value of the elasticity of trade to current income in the period 1950-2000 to be between 1 ad 2.[3] Moreover Bussière *et al.* (2009) and Levchenko *et al.* (2010) argue that the 2008-09 fall of international trade was indeed much deeper than what standard trade models could predict. Additionally the trade collapse was extremely fast and highly synchronised and also involved countries whose economies were not directly hit by the financial crisis.

This surprisingly large drop of trade with respect to income triggered a big debate on its causes. No consensus on the ultimate cause of the collapse has yet emerged. Three possible explanations, which go beyond a straightforward, exogenous increase of the elasticity of trade to GDP, have been proposed: i) compositional effects; ii) trade finance; and iii) vertical specialisation. Those who stress the first driver (such as Levchenko *et al.*, 2010 and Eaton *et al.* 2011) link the smaller decrease of GDP with respect to trade to the high share of services (which were more resilient to the crisis) in domestic production and the predominance of manufacturing and especially of durable goods (which were more severely hit) in international trade. The second approach (Amiti and Weinstein, 2009) argues that the significant reduction of trade credit may have played a role in the fall of imports and exports. This would be especially important because Auboin (2009) estimates that more than 80% of trade relies on trade finance.[4] In this paper we examine, both theoretically and empirically, the third explanation,

[1] We wish to thank Alessandro Borin, Pietro Catte, Virgina Di Nino, Patrizio Pagano, Massimo Sbracia, seminar participants at the Bank of Italy, Brunel University and University of Rome Tor Vergata, and conference participants at the ETSG 2012 in Leuven for their helpful suggestions and comments. All the remaining errors are ours. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Bank of Italy.

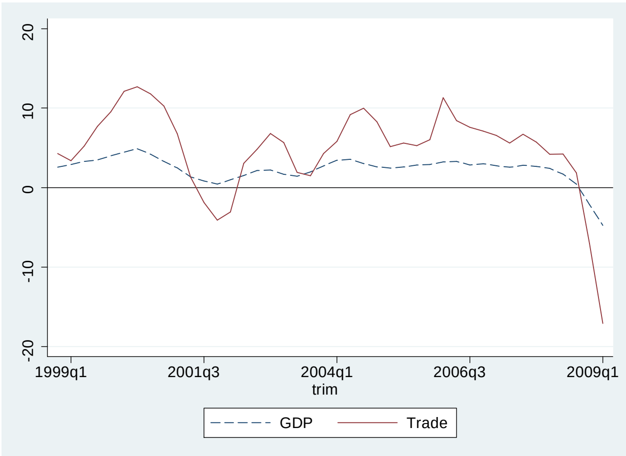
[2] As noted by Eichengreen and O'Rourke (2009) while the fall in industrial production in the 2008-09 crisis was comparable to that which occurred during the Great Depression, trade dropped by a much greater extent. International fragmentation of production may have contributed to this great trade collapse as it did not exist in the 1920s.

[3] Values higher than 3 have only been found in the latter years of the sample by Irwin (2002) and in 1995-2007 by Freund (2009a).

[4] Freund (2009b), however, considers this estimate to be significantly upward biased.

i.e. that vertical specialisation amplified the responsiveness of trade to outcome.[5]

Figure 1: International trade and GDP



Note: Growth rates, quarter on corresponding quarter.

Source: Authors' calculation using OECD data.

We argue that in the presence of a vertically-specialised production process, a shock in the demand for the final good determines a change in the same direction of international flows of the intermediate goods, which may give rise to non-linear effects. Indeed, if the demand shock causes the creation *ex novo* of (or the destruction of existing) international trade links in intermediate goods (this is a change in the *extensive margin* of vertical specialisation), then the change in trade is more than proportional to the change in final demand, i.e. we have a non-linear response of trade to demand. Conversely if the change in final demand is accommodated only by an increase (decrease) in the quantities of intermediate goods flowing through the existing trade links (i.e. the *intensive margin* of vertical specialisation), then the response of trade to demand is linear. Notably, in the first case the elasticity of trade to demand is increased by the change in vertical specialisation whereas in the second it is unaffected by the change.

We present a simple general-equilibrium model which shows that firms adjust the intensive margin of vertical specialisation to accommodate small demand shocks, while a change in their extensive margin is only triggered by large shocks. Thus, given this firms' behaviour, at the macroeconomic level the correlation between vertical specialisation and trade elasticity should be higher in periods of large shocks (*exceptional* times) than in those of small ones (*ordinary* times).

[5]See also Chinn (2005) who attributes the increase in the 2000s of trade elasticity for capital goods to vertical specialisation.

Such a prediction is crucial to test the model even if the unavailability (to our knowledge) of interfirm - year data obliges us to use a measure of vertical specialisation which cannot distinguish between the extensive and intensive margins. In particular, we construct an aggregate index of vertical specialisation based on macroeconomic data which varies over countries and years. We then use this index in a panel analysis on 38 countries between 1998 and 2009 to study the effect of vertical specialisation on the elasticity of trade to demand. We find that trade elasticity is on average positively and significantly influenced by vertical specialisation. More importantly, the effect of vertical specialisation on trade elasticity significantly increases in the exceptional years of our sample, i.e. during the ICT euphoria in 2000 and the 2008-09 crisis. This finding, robust to alternative measures of vertical specialisation, provides strong support to our framework and confirms that vertical specialisation may indeed explain some of the trade collapse.

Other papers explore the link between vertical specialisation and the trade collapse. However, direct comparison with our results is quite difficult as no other paper acknowledges that the effect of vertical specialisation on trade elasticity passes through the extensive margin or exploits the panel structure of the data in a similar manner. Escaith *et at.* (2010) present a thorough investigation of the link between vertical specialisation and elasticity, identifying some channels through which the first may have increased the latter.[6] Their time-series approach leads to the conclusion that international production can explain just some of the trade collapse. Cheung and Guichard (2009) use a measure of vertical specialisation (similar to Escaith *et al.*, 2010, but different from ours) based on data available up to 2005 and estimate a time-series model for world trade, albeit with a different time window. They find a statistically significant, but quantitatively small influence of vertical specialisation on trade in the period from the mid-1970s to the inception of the crisis but they do not estimate its impact on trade elasticity. Bems *et al.* (2010) present a global input-output accounting exercise and show that a higher degree of vertical specialisation implies a higher trade elasticity. In their framework international input-output linkages account for roughly one half of the trade response in the crisis as well as for the co-movement of imports and exports in response to the changes in demand.

The rest of the paper is organised as follows. The next section discusses the link between vertical specialisation and trade elasticity. Section 3 develops the theoretical model. In section 4 we present our measure of vertical specialisation and the econometric analysis. Section 5 concludes.

[6] In particular Escaith *et al.* (2010) stress the roles of the compositional effect and of the inventory adjustment effect (the so-called "bullwhip" effect). whereby inventory adjustments are amplified by the length of the international supply chain.

2 Vertical specialisation and trade elasticity: a discussion

The link between vertical specialisation (VS)[7] and trade elasticity is not easy to grasp. Increasing recourse to vertical specialisation inflates the volume of international trade more than GDP, as the share of transactions in intermediates increases (Yi 2003). Yi (2009) claims that as a direct consequence of this the elasticity of trade to income also increases with VS. O'Rourke (2009) objects that VS cannot increase trade elasticity. We contribute to this debate by clarifying the conditions under which VS does or does not affect trade elasticity.

Vertical specialisation occurs when some phases of a previously integrated production process are moved abroad, while others remain together with the overall coordination in the home country, thus distributring the whole production process along a global network (or value chain). In this context a change in the *extensive margin* of vertical specialisation is a change in the fragmentation network, whereas a change in the *intensive margin* consists in a variation of the quantities flowing through a given production sharing network.[8]

Consider a movement along the intensive margin keeping constant the extensive margin. In this case a given fall in GDP determines an equal percentage decrease in trade of both final and intermediate goods. In other words the elasticity of trade to output, which measures the ratio of the percentage changes, is independent to the degree of vertical specialisation.

Consider now the opposite case in which only the extensive margin changes. Then the response of trade to income is non-linear. In particular, the destruction of fragmentation networks – for instance due to a dramatic fall in the final demand – determines the annihilation of the related trade flows in intermediates. This is the case, for instance, when international production chains are reallocated domestically. Similarly, during boom periods the establishment of new VS networks determines the creation of new trade flows and consequently a

[7] In the economic literature (for a survey, see Breda *et al.*, 2007, and Guerrieri and Vergara Caffarelli, 2005 and references therein) various terms are used to refer to what is essentially the same phenomenon: vertical specialisation, international fragmentation of production, international outsourcing, international production networks, international production sharing. We prefer the first, but we use the others as synonyms.

[8] A change in the network architecture can occur in the case of a re-nationalization of a previously internationally outsourced production phase as well as in the case of the internationalisation of a previously domestic production phase. A change in the identity of the international production partners, however, would not determine a change in the network architecture as the network would still connect the same number of domestic and foreign firms.

more than proportional increase in trade. Hence changes in VS extensive margin[9] affect trade elasticity.[10]

We borrow Jones and Kierzkowski's (1990) simple and intuitive framework to depict a firm's VS choice in figure 2. The solid grey line represents the cost function of the domestically integrated technology, while the solid black line is the cost function of the vertically-specialised production technology. Vertical specialisation determines a reduction in the marginal cost of production (for example because labour-intensive components are imported from cheap-labour countries) and an increase in the fixed costs (for instance due to the establishment and coordination of a geographically-dispersed production network). In this simple model a change in the extensive margin is the switch from a production technology to the other. A change in the intensive margin corresponds to a movement along the same cost function.

The intuition behind this framework is extremely simple. The optimal degree of vertical specialisation depends on the scale of production. For levels of output larger than the quantity identified by the crossing of the vertically-specialised cost function with that of the domestically integrated production, the firm adopts the vertically-specialised production technology, and viceversa. So a large demand shock determines a change in the same direction of the VS extensive margin and consequently a more than proportional change in the volume of trade, hence increasing trade elasticity.[11]

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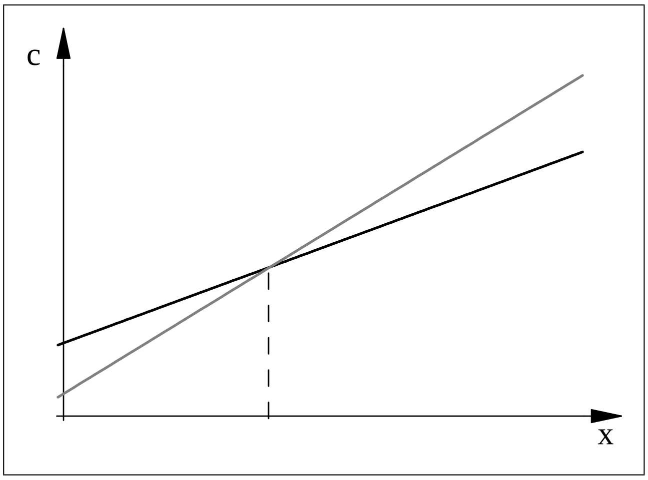
[9] Vertical specialisation may also affect trade elasticity via a compositional effect. For instance, this is the case if fragmented goods represent a higher share in trade than in GDP and the change in the demand for fragmented goods in a cyclical boom is higher than the change in the demand for non-fragmented goods.

[10] When trade flows are measured in volume terms this is the only channel through which elasticity may be affected by VS. Conversely, when trade flows are measured in value terms the elasticity may also depend on the price of intermediates (which may change even holding the fragmentation network constant). However, we believe this effect to be of second order at the aggregate level.

[11] However, it has been suggested that different results could arise if the fixed costs for the adoption of vertically-specialised production technologies are sunk. Altomonte and Ottaviano (2009) conjecture that the presence of (high) sunk costs of fragmentation could cause firms to keep the international supply chain active during a crisis not to destroy the VS network and thus forgo the (sunk) cost. Indeed this could reduce the responsiveness of trade to demand. In this case a non-linear effect of VS on trade would be maintained but would decrease rather than increase the responsiveness of trade to demand shocks.

Figure 2: Total cost in case of integrated or vertically-specialised production



In the next section we present a simple general equilibrium model which incorporates our intuition on VS. In particular our framework will consider the cases of significant demand shocks in either direction which we will refer to as "euphoria" and "crisis".

3 A model of vertical specialisation

Building on Burda and Dluhosch (2002) we propose a model which captures the main features of the link between VS and the demand for final goods. The purpose of the model is to show how optimising firms adjust the intensive and extensive margins of vertical specialisation in response to demand shocks. In order to clarify the mechanics of the adjustment we proceed in two steps. We first present a simplified version of the model in which firms optimally respond to demand shocks by changing the extensive margin of vertical specialisation. We then extend the framework to allow for the optimal choice to occur along both margins. In this way we show that the response to large demand shocks takes place through the extensive margin whereas small shocks are accommodated along the intensive margin.

Consider a general-equilibrium model of the world economy in which there are four commodities: an agricultural good, a final good, a constructed intermediate good and fragmentation services. The only factor of production is labour and there is no accumulation. Households maximise a standard utility function that combines a constant-return-to-scale Cobb-Douglas function over the quantity of an agricultural good, x_0, and a C.E.S. aggregate of the quantities of N horizontally differentiated manufactured goods, x_i:

$$U = x_0^{1-\mu}\left(\sum_{j=1}^{N} x_j^{\frac{1-\eta}{\eta}}\right)^{\frac{\mu\eta}{1-\eta}}$$

where $\mu > 0$ and $(1-\mu) > 0$ are the expenditure shares of the composite manufactured good and the agricultural good respectively and $\eta > 1$ is the elasticity of substitution between manufactured goods. The agricultural good is the *numeraire* of the economy. As usual the consumer demand is: $x_0 = (1-\mu)Y$ for the agricultural good and $x_i = p_i^{-\eta}P^{\eta-1}\mu Y$ for the manufacturing good where $P = \left(\sum_{j=1}^{N} p_j^{1-\eta}\right)^{1/(1-\eta)}$ is the C.E.S. price index.

The perfectly competitive agricultural sector employs labour with a marginal productivity of 1. Manufacturing firms face Dixit-Stiglitz (1977) monopolistic competition in the market for the final good. As we focus on the short-run equilibrium the number of firms, N, is given. The production of each variety of the final good, x_i, requires as inputs the intermediate good, t_i, and fragmentation services, z_i, combined in a Cobb-Douglas production function with increasing returns to scale:[12]

$$x_i = \theta t_i z_i^{\gamma} \tag{1}$$

where $\gamma \in (0,1)$ and $\theta > 0$ is the total factor productivity. Input prices are p_t and p_z. Both the fragmentation service sector and the intermediate good sector are perfectly competitive, display constant returns to scale and employ only labour, with marginal productivity $\alpha > 0$ and $\beta > 0$, respectively.

The total cost of production for manufacturing firm i is trivially $C_i = p_t t_i + p_z z_i$, i.e. the total expenditure in inputs. Substituting the intermediate good requirement obtained from the production function (1) the total cost becomes:

$$C(x_i, z_i) = \frac{v}{z_i^{\gamma}} x_i + p_z z_i \tag{2}$$

where $v = \frac{p_t}{\theta}$. Equation (2) shows the effect of VS on total production costs. An increase in fragmentation service input, z_i, reduces the marginal cost of production, v/z_i^{γ}, and raises the fixed cost, $p_z z_i$, for each variety of the final good. The cost function (2) generalises in a continuous framework the original intuition

[12] The results remain unchanged if we postulate that manufacturing goods are produced with fragmentation services and labour, instead of an intermediate good. However, in this case the model would focus on the choice of a firm between vertical integration and fragmentation. We prefer the current formulation because it clearly identifies both the extensive and the intensive margins of fragmentation.

by Jones and Kierzkowski (1990) described in section 2. Assuming that VS services can take only two levels, z_L and z_H, we have the cost functions depicted in figure 2.[13] The advantage of this modelling choice is a higher generality as well as a greater analytical tractability. Notice that a change in z corresponds to a differently fragmented production technology. In the terminology of the previous section it corresponds to a change through the extensive margin of VS. A change in the intensive margin would correspond to a change in the intermediate good input, t_i, for a given level of z_i. As z_i is a continuous variable and in this version of the model it can be changed at no cost, it will be optimally chosen for every level of output. Consequently no change in intensive margin will occur here.

We indicate with L the given supply of homogeneous labour in the economy, which is perfectly mobile across sectors. Hence the wage is unique and equal to 1, because of the normalisation of the output price and and the assumption about labour productivity in agriculture. It follows that the price of the intermediate good and of fragmentation services are respectively $p_t = \frac{1}{\beta}$ and $p_z = \frac{1}{\alpha}$.

The profit function of firm i is

$$\pi_i (p_i, z_i) = p_i x_i (p_i) - \left(\frac{v}{z_i^\gamma} x_i (p_i) + p_z z_i \right)$$

For any good we can solve the model in the level of fragmentation services, z. From profit maximisation (and symmetry) we obtain usual markup pricing rule $p = \frac{\eta}{\eta-1} \frac{v}{z^\gamma}$ and optimal quantity $x = \frac{\eta-1}{\eta} \frac{\mu Y}{N} \frac{z^\gamma}{v}$ both as a function of z.

To compute the equilibria of the intermediate good sector and of the fragmentation service sector we equate demand and supply in each market $N \frac{v}{z^\gamma} x = p_t \beta l_t$ and $Nz = \alpha l_z$. From these we obtain the non-agricultural labour demands which combined with the agricultural labour requirement, $l_0 = (1-\mu) Y$, fully exhaust the inelastic supply of labour. Solving the labour-market equilibrium condition for household income Y, we have:

$$Y = \frac{L - N \frac{z}{\alpha}}{1 - \mu + \frac{\eta-1}{\eta} \mu} \tag{3}$$

Let us now determine the equilibrium level of VS services. The level of VS is chosen by the manufacturing firms in the profit maximisation problem. From $\frac{\partial \pi_i}{\partial z_i} = \gamma v z_i^{-1-\gamma} p_i^{-\eta} P^{\eta-1} \mu Y - p_z - \delta = 0$ and symmetry we obtain $z = \left(\frac{\gamma v \mu Y}{N p_z p} \right)^{1/(1+\gamma)}$ which combined with (3) gives

$$z^* = \frac{(\eta - 1) \alpha \gamma \mu L}{(\eta - \mu + \gamma \mu (\eta - 1)) N} \tag{4}$$

[13] We have to allow for a minimum extent of fragmentation as in the model the marginal cost of production is infinite for a zero level of fragmentation.

which is the optimal level of vertical specialisation. As in Burda and Dluhosch (2002) an increase in the labour endowment – which we interpret as globalisation with no trade costs – increases the optimal level of VS. An increase in the marginal productivity of labour in the fragmentation services sector has the same effect, as the VS sector becomes more efficient and fragmentation services cheaper. An increase in the number of firms reduces z^* because it determines a reduction in the output produced by each manufacturing firm which consequently adjusts downwards the extensive margin of fragmentation.

Combining equations (3) and (4), the markup pricing rule and the demand curve for the final good we obtain the optimal level of the manufacturing output:

$$x^* = \frac{(\alpha\gamma)^\gamma}{v} \left(\frac{(\eta - 1)\,\mu L}{(\eta - \mu + \gamma\mu\,(\eta - 1))\,N} \right)^{\gamma+1} \tag{5}$$

which is increasing in the labour endowment and in the marginal productivity of labour in the VS sector and decreasing in the number of varieties for the same reasons explained above for z^*. Recalling that $v = \frac{p_t}{\theta} = (\beta\theta)^{-1}$, x^* is also an increasing function of both the total factor productivity in the final good sector and of the labour productivity in the intermediate sector.

In order to appreciate the effect of a demand shock to the equilibrium levels of VS and of production, we take the derivatives of equations (4) and (5) with respect to the preference parameter μ which measures the relative preference on the manufactured good with respect to the agricultural good:[14]

$$\frac{\partial z^*}{\partial \mu} > 0 \quad \text{and} \quad \frac{\partial x^*}{\partial \mu} > 0 \tag{6}$$

which are both positive for all parameter values.[15] Equation (6) indicates that firms optimally respond to demand shocks by varying production levels and the extensive margin of fragmentation in the same direction as the shock.[16] One implication of this simplified version of the model is that demand shocks determine a change in production levels, no adjustment along the fragmentation intensive margin and a movement of VS extensive margin. As argued in the previous section movements of VS extensive margin do affect elasticity of trade to income. Note, however, that every demand shock, large or small, would trigger this effect. Consequently no differentiated response of the elasticity would occur

[14] A change in the elasticity of substitution among the varieties of the manufactured good would not affect the expenditure shares between agricultural and manufactured goods.

[15] The derivatives are $\frac{\partial x^*}{\partial \mu} = \frac{L}{Nv} \frac{\eta(\gamma+1)(\eta-1)}{(\mu-\eta+\gamma\mu-\gamma\mu\eta)^2} \left(\frac{\alpha\gamma(\eta-1)L\mu}{N(\eta-\mu+\gamma\mu(\eta-1))} \right)^\gamma$ and $\frac{\partial z^*}{\partial \mu} = \frac{L}{N} \frac{\alpha\gamma\eta(\eta-1)}{(\mu-\eta+\gamma\mu-\gamma\mu\eta)^2}$.

[16] This is a key difference with respect to Altomonte and Ottaviano (2009) who conjecture that the response is in the opposite direction.

in “normal” and “exceptional” times. To allow for this distinction we need to extend the model and in particular to modify the role for the intensive margin of fragmentation.

Let us now assume that every change in z_i determines an additional cost proportional to z_i. So the new cost function for manufacturing firm i is:

$$\hat{C}(x_i, z_i) = \frac{v}{z_i^{\gamma}} x_i + p_z z_i + \delta z_i I_{\{\Delta z_i \neq 0\}} \tag{7}$$

where $\delta > 0$ is the unit adjustment cost and the indicator function I takes value 1 if $\Delta z_i \neq 0$ and 0 otherwise. The intuition behind the formula is straightforward: more fragmented organisations are more complex and hence more expensive to modify, so the adjustment cost is proportional to the initial level of fragmentation services. The model can be solved as the one without adjustment cost.

The optimal level of VS services is:

$$\hat{z} = \frac{(\eta - 1)\,\alpha\gamma\mu L}{((1 + \alpha\delta)(\eta - \mu) + \gamma\mu(\eta - 1))\,N} \tag{8}$$

and the optimal quantity of the manufacturing good is:

$$\hat{x} = \frac{(1 + \alpha\delta)(\alpha\gamma)^{\gamma}}{v} \left(\frac{(\eta - 1)\,\mu L}{((1 + \alpha\delta)(\eta - \mu) + \gamma\mu(\eta - 1))\,N} \right)^{\gamma + 1} \tag{9}$$

which, as before, are both increasing in μ:

$$\tfrac{\partial \hat{z}}{\partial \mu} > 0 \quad \text{and} \quad \tfrac{\partial \hat{x}}{\partial \mu} > 0 \tag{10}$$

given parameters' values.[17] Note that the previous model is a special case of the current, for $\delta = 0$.

Unlike in the previous model, equation (10) is not enough to assess the effect of a demand shock. The presence of a positive adjustment cost for VS services may cause the optimal response to small shocks to be no adjustment at all. In order to clarify the interaction between the intensive and extensive margins of vertical specialisation we perform some comparative statics on the equilibrium $(\hat{x}, \hat{z})$. As before, assume a shock in the preference parameter μ. In responding to such a demand shock the key choice for a firm is whether or not to adjust VS services input to the level required by the new demand. Intuitively the firm faces the following problem: change z to the level required by the post-shock optimal output (paying the adjustment cost) or keep z fixed (and pay a higher production cost due to the non-optimal vertical specialisation level). As we will

[17] The derivatives are $\frac{\partial \hat{x}}{\partial \mu} = \frac{L\eta(\gamma+1)(\eta-1)(\alpha\gamma)^{\gamma}(\alpha\delta+1)^2\left(\frac{L}{N}\mu\frac{\eta-1}{(1+\alpha\delta)(\eta-\mu)+\gamma\mu(\eta-1)}\right)^{\gamma}}{Nv((1+\alpha\delta)(\eta-\mu)+\gamma\mu(\eta-1))^2}$ and $\frac{\partial \hat{z}}{\partial \mu} = \frac{(\eta-1)(\alpha\delta+1)\alpha\gamma\eta L}{(\eta-\mu+(\alpha\delta+\gamma\mu)(\eta-1))^2 N}$.

show, in the model large demand shocks imply a change in the extensive margin while small shocks are accommodated along the intensive margin.

To determine the optimal choice of the firm we compare profits attained adjusting both output and VS services to the new optimal level associated with the new demand, with profits earned keeping fragmentation service fixed at $\hat{z}$ and adjusting output only. As revenues do not depend on VS input we will only need to focus on the cost function.

To construct the first term of comparison, consider firm i's optimisation problem in terms of production output and VS level

$$\max_{x_i, z_i} \hat{\pi}_i(x_i, z_i) = p_i(x_i)\, x_i - \hat{C}(x_i, z_i)$$

where $p_i(x_i)$ is the inverse demand function for manufacturing good i. Rather than solving the problem simultaneously in both x_i and z_i we maximise in z_i only. The F.O.C. is:

$$-\frac{\partial}{\partial z_i}\hat{C}(x_i, z_i) = \gamma \frac{v}{z_i^{\gamma+1}} x_i + \frac{1}{\alpha} + \delta = 0$$

from which we obtain

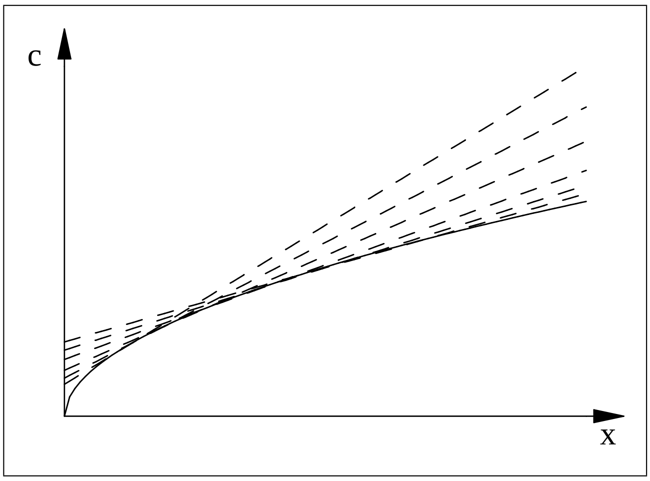
$$\tilde{z}_i(x_i) = \left(\frac{\gamma \nu}{\frac{1}{\alpha} + \delta}\right)^{\frac{1}{1+\gamma}} x_i^{\frac{1}{1+\gamma}}$$

which indicates for each level of production the optimal requirement of VS services. Plugging in $\tilde{z}_i(x_i)$ into the cost function (7) we obtain

$$\tilde{C}(x_i) = \hat{C}(x_i, \tilde{z}_i(x_i)) = \nu^{\frac{1}{1+\gamma}} \left(\frac{\gamma}{\frac{1}{\alpha} + \delta}\right)^{-\frac{\gamma}{1+\gamma}} \left(\frac{\gamma}{\alpha\delta + 1} + 1\right) x_i^{\frac{1}{1+\gamma}} \tag{11}$$

which is the envelop of $\hat{C}(x_i, z_i)$ with respect to z_i. Equation (11) represents the cost of production for every level of x_i when VS services are optimally adjusted to the level of output. Figure 3 below shows the envelop cost function and the linear cost functions (including the adjustment costs) for different levels of fragmentation.

Figure 3: Envelop cost function and technologies with different VS levels



Let us now consider the second term of comparison. Now the firm chooses not to adjust the VS level. Then its linear cost function is:

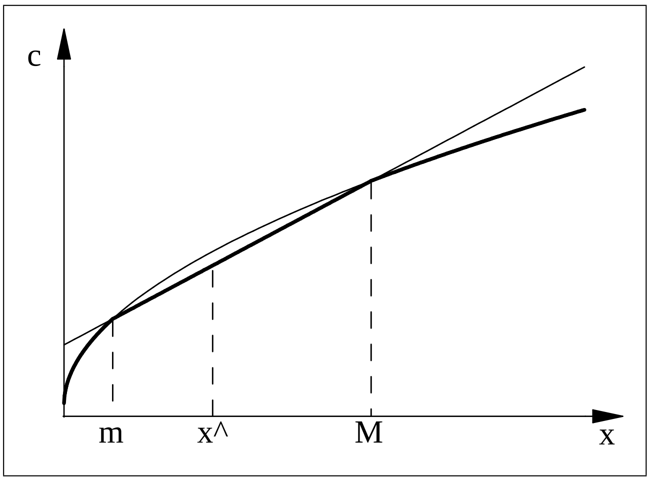
$$C\left(x_i|\hat{z}\right) = \frac{v}{\hat{z}^{\gamma}}x_i + \frac{1}{\alpha}\hat{z} \tag{12}$$

obtained from equation (7) for $\Delta z_i = 0$ and $z_i = \hat{z}$ as in equation (8).

The optimal choice of whether or not to adjust VS is obtained by minimising production costs for each output level. Solving $\tilde{C}\left(x_i\right) \leq C\left(x_i|\hat{z}\right)$ we obtain the threshold values m and M such that $\tilde{C}\left(x_i\right) > C\left(x_i|\hat{z}\right)$ for $x_i \in (m, M)$ and $\tilde{C}\left(x_i\right) < C\left(x_i|\hat{z}\right)$ for $x_i < m$ or $x_i > M$ (this is formally proven in Appendix A).

The choice of a firm is illustrated in figure 4 below. The line depicts equation (12) and the curve the envelop (11). The cost function derived from the optimisation of the level of vertical specialisation is in bold. The response to a demand shock to the equilibrium $(\hat{x}, \hat{z})$ for which the new level of output lies within the interval (m, M) is along the intensive margin because z is kept constant at its pre-shock level, $\hat{z}$. Instead larger shocks (for which the output level goes outside the interval) are accommodated by paying the adjustment cost and changing z.

Figure 4: Optimal choice of the extensive and the intensive margin of vertical specialisation



Thus the model shows that in exceptional times, i.e. during periods of "crisis" (a reduction of x below m) or "euphoria" (an increase of x above M), a demand shock causes a change in the extensive margin of the firm; conversely in ordinary times, i.e. when the new demand lies in the interval $[m, M]$, the shock is accommodated along the intensive margin. Such firms' differentiated response to the size of the shock determines the non-linearity at the macroeconomic level: international trade becomes more responsive to world income during exceptional periods and consequently the correlation between trade elasticity and vertical specialisation is higher.

The model can be extended further assuming firms' heterogeneity in the adjustment costs. In this case the effect of a demand shock on the change of the other aggregate variables would be less sharp, but the main features would remain. Indeed, small shocks would trigger a change in extensive margin of vertical specialisation only for a small number of firms while larger shocks would cause (most of) the firms to adjust. At the macroeconomic level the correlation between trade elasticity and vertical specialisation will be higher in exceptional times.

4 Empirical analysis

Ideally in order to properly verify the role of VS on trade elasticity in our framework, it would be necessary to construct country-year measures of both the intensive and extensive margins of VS. For this purpose we would need to collect (and aggregate) data on the change in international flows of intermediate goods for every pair of exporting- and importing-firm in all the countries of interest. In this way we can observe the substitution of domestic suppliers with foreign ones and viceversa. The ideal regression would then correlate trade elasticity with the intensive and extensive margins of vertical specialisation. The framework would be verified if the coefficient of the former were not significant, and that of the latter significantly positive and higher in exceptional years.[18]

Alas, such firm-level data are not available, hence we adopt a different approach.[19] We first construct an index of vertical specialisation at the country-year level, using bilateral flows in intermediate and total trade. Obviously, this index does not distinguish between the extensive and intensive margins. We then estimate the correlation between trade elasticity and our aggregate VS index and find that during the exceptional years in our sample (2000 and 2009) it is higher than in the other (ordinary) years. Although we cannot formally attribute this effect to the extensive margin, we argue that this is the case. Indeed: i) we know that only a change in VS extensive margin determines an increase in trade elasticity, thus the empirical results indicate that the extensive margin changed during those exceptional years;[20] ii) our model shows that only VS extensive margin is adjusted during extraordinary times while in ordinary times only changes in VS intensive margin occur. There is some anecdotal evidence on firms' adjustment of VS extensive margin during the trade collapse that supports our interpretation of the results. Indeed Escaith (2009) and Freund (2009a) document the re-nationalisation of some global supply chains during the 2008-09 crisis. Additionally, note that even in normal times trade elasticity may be affected by VS: international networks may continuously adjust in the extensive margin. The interest in studying the response in exceptional times rests in the fact that the extensive margin then changes to a significantly larger extent.

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[18] Moreover, it would be possible to test directly the model's prediction that firms adjust the extensive margin during exceptional times and the intensive one in ordinary periods.

[19] A possible indirect way to measure the extensive margin with aggregate data is to calculate the number of bilateral trade links among countries. This measure, however, significantly underestimates the actual VS extensive-margin change as it does not capture all changes at firm level which do not fully annihilate the trade flow between two countries.

[20] Counting the number of bilateral trade links in the global trade network, De Benedictis and Tajoli (2010) show that this number fell dramatically in the first quarter of 2009. Even if they consider total trade (i.e. they do not distinguish between intermediate and final goods), this finding confirms a change in the VS extensive margin during the trade collapse. As intermediate trade flows are a subset of total trade, the annihilation of the latter implies that of the former.

4.1 A measure of vertical specialisation

To measure vertical specialisation in advanced and emerging-market economies we propose a variant of the Revealed Comparative Advantage Index introduced by Balassa (1965). This index compares the share of trade in intermediate goods for each country with the trade share in intermediates for the whole world. In order to capture the different features of vertical specialisation we compute two measures: one based on exports of intermediate goods and the other on imports. The two indices are defined in the following equations:

$$VS(\exp)_{i,t} = \frac{\sum_{j\in S} X^{\mathrm{Int}}_{i,j,t} / \sum_{j\in S} X^{\mathrm{Tot}}_{i,j,t}}{\sum_{i,j\in S} X^{\mathrm{Int}}_{i,j,t} / \sum_{i,j\in S} X^{\mathrm{Tot}}_{i,j,t}} \tag{13}$$

$$VS(\mathrm{imp})_{i,t} = \frac{\sum_{j\in S} M^{\mathrm{Int}}_{i,j,t} / \sum_{j\in S} M^{\mathrm{Tot}}_{i,j,t}}{\sum_{i,j\in S} M^{\mathrm{Int}}_{i,j,t} / \sum_{i,j\in S} M^{\mathrm{Tot}}_{i,j,t}} \tag{14}$$

in which X are exports, M imports, the superscripts Int and Tot refer to intermediate-good and total trade flows respectively, t is time, i is the country whose exports (imports) are considered, j the partner countries and S is the set of countries under analysis.[21] Oil and agricultural commodities have been excluded from total trade to minimise the effect of their price volatility on trade values. Both indices take non-negative values (equal to zero only in the event that the country does not trade in intermediate goods). The reference value for both indices is one: for values higher (lower) than one, the country is relatively (de)specialised in the trade of intermediate goods with respect to the world. We interpret an index above 1 as an indication that production in country i is vertically specialised. In particular, $VS(\exp)_{i,t}$ measures the degree of country i's specialisation in the production and export of intermediate goods while $VS(\mathrm{imp})_{i,t}$ deals with the relative specialisation in the assembly operations of final goods using imported intermediates. Vertical specialisation from the intermediate producers' side is well captured by the $VS(\exp)_{i,t}$ index, since we exclude re-exports (as well as re-imports) from the data. However, the $VS(\mathrm{imp})_{i,t}$ index may be less precise in measuring vertical specialisation for the final good assemblers' side, because intermediate imports may also be used for consumption and as spare parts.

The complexity of the issue under study emerges quite clearly from an examination of the two indices.[22] Both measures exhibit significant variability across countries and years. In some economies both take values greater than

[21] The countries analysed in this paper are listed in Appendix B.

[22] Appendix C collects the plots of the two indices for some countries.

one. These countries may be producing and exporting intermediate goods and simultaneously assembling final goods using imported intermediates. Indeed not only may the relative role in the international division of labour differ within the same country in various sectors but also an economy may place itself in an intermediate position (between the production of intermediates and assembly of final goods) in the international production chains.

We have consequently chosen to use $VS(\exp)_{i,t}$ for countries predominantly defined as intermediate-good producers and $VS(\text{imp})_{i,t}$ for those specialised in the assembly of final goods.[23] In defining the role of the countries under analysis we resorted to outside information. Our basis assumption is that advanced countries are intermediate-good importers and assemblers of final goods whereas emerging-market economies are producers and exporters of intermediates.[24] There are, however, three important exceptions: China and Mexico are classified among final-good assembling countries and the USA are included among the producers of intermediate goods.[25] This classification is supported by the fact that $VS(\exp)_{i,t}$ is on average higher than $VS(\text{imp})_{i,t}$ for countries in the group of producers of intermediates.

Therefore, in the regressions we use an index of vertical specialisation which considers the share of intermediate goods in imports for assemblers of final goods and in exports for producers of intermediates (and compares it with the corresponding share in world trade):

$$VS_{i,t} = \begin{cases} VS(exp)_{i,t} & \text{if } i \in P \\ VS(imp)_{i,t} & \text{if } i \in A \end{cases} \qquad (15)$$

in which A and P are the set of final-good assembling countries and of intermediate-good producers, respectively. The index $VS_{i,t}$ incorporates our hypothesis on the international division of labour among the different economies.[26]

We use data drawn from various sources. Total international trade in current dollars comes from the OECD, while the value of trade in intermediates is taken from UN Comtrade. According to the Broad Economic Categories Classification intermediate goods are Processed food and beverages mainly for industry, Primary and Processed industrial supplies not elsewhere specified, Processed

[23] Moreover, the strong correlation between the two indices advises against their simultaneous presence in a regression model.

[24] The distinction between advanced and emerging market countries is based on the World Bank's classification of economies by income.

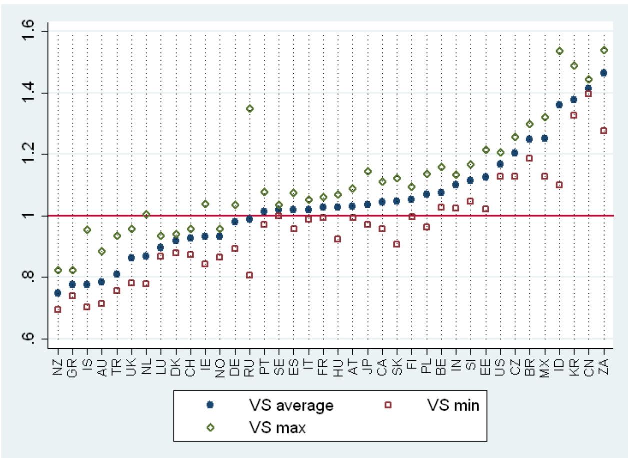
[25] This choice for the USA and Mexico is based on the evidence of the *maquilladoras* (Mexican duty-free assembly plants); for China, see Asian Development Bank (2009, p. 39).

[26] This working hypothesis is empirically tested in the regressions [1] and [2] (table 2 in Appendix D).

fuels and lubricants (other than motor spirit), Parts and accessories of capital goods (except transport equipment), and Parts and accessories of transport equipment.[27] Data on nominal GDP in local currency and exchange rates with the US Dollar come from the IMF. The combined data set contains annual observations for 38 countries for the period from 1998 to 2008 and for the first quarter of 2009.

In our sample the average VS degree of the producers of intermediates significantly increased from 1.01 in 1998 to 1.16 in 2004, stabilising at around 1.12 from then on. Final-good assemblers, instead, displayed a constant value of about 1.01 in the period 1998-2003, which afterwards declined to 0.97. Moreover, the index presents significant variability both between and within countries. This can be seen in figure 5 which presents the average, minimum and maximum of the index in the period for each country. The measure of vertical specialisation reaches it minimum (0.69) in New Zealand in 2007 while the maximum (1.54) is in 2007 in South Africa. Country averages range from 0.75 (New Zealand) to 1.46 (South Africa). The range between the minimum and maximum values of $VS_{i,t}$ also varies significantly across countries. It is quite large in the cases of Russia and Indonesia (greater than 0.4) and very small in Sweden and China (less than 0.05). Thus there is substantial between- and within-variability of $VS_{i,t}$ which will be exploited in the econometric strategy in the following section.

Figure 5: Index of vertical specialisation



Source: Authors' calculation using UN Comtrade data.
Note: max, min, and average for each country over the sample period.

[27] With respect to the UN Comtrade definition of intermediate goods we actually exclude primary food and beverages mainly for industry and primary fuels and lubricants, which are more properly commodities rather than intermediates.

4.2 Regression results

We define the instant elasticity of trade to world demand as the percentage variation of each country's total trade (imports plus exports) over the percentage variation of the other countries' GDP.[28] This is the dependent variable in our econometric analysis. Table 1 in Appendix D contains the summary statistics of the variables used in regressions. The average trade elasticity is .87. This number is not perfectly comparable with the elasticity discussed in section 1 because the former is the average of the elasticities in the period 1999-2009 across countries while the latter is the elasticity of world trade with respect to global income.

We first proceed to the empirical validation of our hypothesis on the international division of labour underlying the construction of the $VS_{i,t}$ measure. This is done by estimating two equations. The first is:

$$\eta_{i,t} = \alpha_1 d_i^P VS(\exp)_{i,t-1} + \alpha_2 d_i^A VS(\exp)_{i,t-1} + \delta_i + \varepsilon_{i,t} \tag{16}$$

in which the regressors are lagged $VS(\exp)_{i,t}$ and country fixed effects δ_i, and the dependent variable $\eta_{i,t}$ is trade instant elasticity. The measure of VS is interacted with a dummy which indicates the role of each country in the international supply chain: d_i^P for producers of intermediates and $d_i^A = \left(1 - d_i^P\right)$ for final-good assemblers. If the measure is correct we expect the coefficient α_1 to be significantly greater than zero and α_2 close to 0. The second equation is identical to (16) except that we replace $VS(\exp)_{i,t}$ with $VS(\text{imp})_{i,t}$. Here we expect only the coefficient of the interaction term with the assembler-dummy to be significant. The outcome of the first two regressions (columns [1] and [2] in table 2 in Appendix D) partially supports our hypothesis on the different roles of countries in the international supply chain. Equation (16) fully validates the assumption regarding the intermediate producers: the export-VS index is significantly correlated with the trade elasticity of those countries which produce intermediate goods, while it is not correlated with the elasticity of the assemblers. The validation for the assemblers (column [2]) is less clear since the import-VS index is positively, but insignificantly, correlated to trade elasticity of final-good assembling countries. However, this is consistent with the weaker precision of $VS(\text{imp})_{i,t}$ noted above. Thus we maintain this hypothesis in the main econometric analysis, postponing its disposal to the robustness exercises, where we will show that the main results are fully confirmed.

We estimate the effect of $VS_{i,t}$ on trade elasticity both on average and distinguishing between ordinary and exceptional times. In the regressions, which

[28] Our definition of instant elasticity is fully appropriate for exports while for imports it may be desirable to augment it with the county's own GDP. As a robustness exercise we used this alternative definition: the main empirical results are confirmed.

include other control variables, we use the first lag of the degree of vertical specialisation to take into account possible simultaneity problems. We estimate three different equations.

We first regress trade elasticity on lagged $VS_{i,t}$ and country fixed effects:

$$\eta_{i,t} = \beta VS_{i,t-1} + \delta_i + \varepsilon_{i,t} \tag{17}$$

The estimation results of equation (17) are reported in column [3] (table 2 in Appendix D). Controlling for country fixed effects, $VS_{i,t}$ is positively and significantly correlated with trade elasticity. The coefficient (of 2.2) implies that as we move from the 25th to the 75th percentile of the $VS_{i,t}$ distribution (increasing its $VS_{i,t}$ index by 0.21), the trade elasticity to global demand would increase by 0.45. This amount corresponds to a 52% increase of the sample average elasticity (0.87).

Second, as a robustness check we estimate an equation in which we augment the specification (17) with year fixed effects. Our results are confirmed (column [4]). Year fixed effects absorb all the shocks simultaneously affecting the 38 countries. In particular they control for country-invariant events such as the global business cycle as well as global trade shocks, e.g. changes in transportation costs or the global component of trade-finance shock.[29]

Previous regressions suggest that countries experiencing larger-than-average changes in vertical specialisation display a higher trade elasticity. Our theoretical analysis implies that the correlation between VS and elasticity increases in exceptional periods, since firms respond to large demand shocks by adjusting the VS extensive margin. Our time span includes two global extraordinary events: the ICT euphoria (2000)[30] and the global crisis.[31] We expect these two years to stand out quite distinctly in the regression.

For this purpose we let the coefficient of $VS_{i,t}$ vary year by year:

$$\eta_{i,t} = \beta VS_{i,t-1} + \sum\nolimits_{\tau=1999}^{2008} \gamma_\tau \delta_\tau VS_{i,\tau-1} + \delta_i + \varepsilon_{i,t} \tag{18}$$

where the $VS_{i,t-1}$ coefficient, β, captures the effect of vertical specialisation on trade elasticity in the reference year, 2009. The coefficients γ_t of the interaction

[29] Some residual noise may be left in the estimates due to the effect of price and exchange rate changes.

[30] In 2000 the ICT euphoria reached its peak. There was a widespread perception that the diffusion of ICT could generate an ever increasing labour productivity. On 10 March 2000 the Nasdaq Composite Index reached its all-time high: 5048.62.

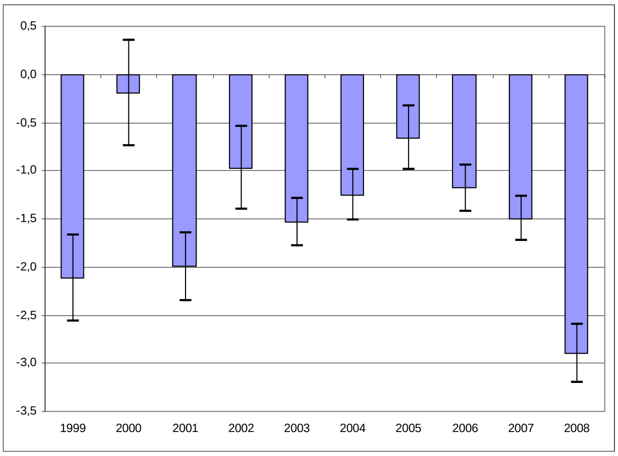
[31] 2001 was another potentially exceptional year, because of the September 11 attacks and the recession in the USA. As noted by the CEPR (2003) there was no recession in the euro area and hence 2001 was not a globally exceptional year.

terms of $VS_{i,t}$ with year dummies, δ_t, instead, capture the way the effect of vertical specialisation differs in each year with respect to 2009. The estimates are in column [5]. As expected in each year of our sample the contribution of VS to trade elasticity is significantly lower than in the reference period. This confirms the exceptionality of the crisis events that affected the extensive margin of fragmentation and hence the trade elasticity. Figure 6 depicts the difference of the VS effect in every year with respect to 2009 together with the 5% confidence interval. The figure shows another finding which is consistent with our framework. The coefficient of $VS_{i,t}$ interacted with the dummy 2000 is not statistically different from that on 2009.

Finally, for every year we can compute the partial effect of $VS_{i,t}$ in that year, which is the sum of the coefficients of $VS_{i,t}$ and of the year interaction term. Partial effects represent the net impact of vertical specialisation in the year and are presented in table 3. As discussed above the greatest effects are in 2000 and 2009. The effect in 2008 is negative because the elasticity of trade to income was negative that year, but not significantly different from zero ($t = -0.19$; p-value $= 0.85$).

In conclusion, the econometric analysis uncovers a positive correlation between trade elasticity to world demand and (the extensive margin of) vertical specialisation. This correlation is, as expected, much stronger during exceptional times such as the ICT euphoria and the 2008-09 crisis.

Figure 6: Difference of the yearly effect of vertical specialisation



Note: Difference with respect to the effect in 2009, with 5% confidence intervals.

4.3 Robustness: alternative measures of vertical specialisation

In this section we check that our results are robust to different measures of vertical specialisation which overcome two possible concerns with the $VS_{i,t}$ measure. Our first and main caveat rests with the relative nature of a Balassa-type index. By construction it captures how much each country is specialised in exporting or importing intermediates with respect to the world average in a given year. Thus $VS_{i,t}$ accounts well for cross-sectional variability of fragmentation but it is much less powerful in taking into account its time-varying component. The use of this measure in our framework could possibly bias the results, via the elimination of the time-series component of the panel. Indeed regressions in section 4.2 may be considered as a repeated cross-section analysis.

To take fully into account this observation, we depart from Balassa (1965) and we measure vertical specialisation through the country's share of export (import) of intermediate goods in its total export (import) – that is the numerator of the VS index in equation (15). We refer to this index as the intermediate share, $IS_{i,t}$. The drawback of this measure is the lack of a comparison group: a given time pattern of the intermediate share of one country does not allow us to infer whether the country became more or less involved in production sharing activities than the rest of the world. By its absolute nature, this index is less precise in capturing the role of a country in the international supply chain. With this measure of fragmentation we expect to find a stronger effect along the temporal dimension due to its higher time variability.

Table 4 in Appendix D presents the results of our set of regressions using the $IS_{i,t}$ measure (instead of the $VS_{i,t}$).[32] A simple inspection of the table shows that the validation hypothesis regressions (columns [1] and [2]) confirm those in table 2: the validation equation for producers of intermediates fully passes the test, while the validation for final-good assemblers is less powerful since, as before, the coefficients are not statistically significant (and in this case they also have the wrong sign). As to the empirical analysis, we find that, although in the simple regression with only fixed effects (column [3]), $IS_{i,t}$ does not explain trade elasticity, once year fixed effects are included (column [4]) our absolute measure of vertical specialisation is strongly correlated with trade elasticity and the differential effect for normal and extraordinary years (2000 and 2009) is fully confirmed (column [5]). In particular, the effect is even stronger than the one obtained with a relative measure and the significance level is very high.

The second caveat with our VS (and with IS measure as well) is that it rests on our international labour division hypothesis: emerging-market economies, with

[32] These are: validation equation (16), its import-based counterpart, elasticity equation (17), its year-fixed-effect augmented specification and the time-varying coefficient model (18).

the exception of China and Mexico, are producers and exporters of intermediate goods, whereas advanced countries, with the exception of the USA, assemble final goods using imported intermediates. We find this assumption reasonable and we indeed verify that it empirically holds. It could, however, be objected that our results are biased because they are based on an index of vertical specialisation which incorporates this assumption.

As a solution we measure VS considering a country's total trade in intermediates, instead of exports and imports separately. We now compute another Balassa (1965) - type Revealed Comparative Advantage Index for intermediate goods calculated on total trade flows (instead of imports or exports only).[33] In particular we use the following:

$$VS(\text{trade})_{i,t} = \frac{\sum_{j \in S} \left(X^{\text{Int}}_{i,j,t} + M^{\text{Int}}_{i,j,t} \right) \Big/ \sum_{j \in S} \left(X^{\text{Tot}}_{i,j,t} + M^{\text{Tot}}_{i,j,t} \right)}{\sum_{i,j \in S} \left(X^{\text{Int}}_{i,j,t} + M^{\text{Int}}_{i,j,t} \right) \Big/ \sum_{i,j \in S} \left(X^{\text{Tot}}_{i,j,t} + M^{\text{Tot}}_{i,j,t} \right)} \tag{19}$$

where, as usual X are exports, M imports, the superscripts Int and Tot refer to intermediate-good and total (excluding commodities) trade flows respectively, t is time, i and j are the country indices and S is the set of countries. Rather than distinguishing between the different roles that a country may play in the international production chain, the index (19) measures VS as the overall involvement in trade of intermediate goods, both on the import and on the export side. Values greater than one indicate a relative specialisation of the country in the trade of intermediates which is evidence of engagement in international production sharing.

With this measure we do not need to estimate the validation equations, since $VS(\text{trade})_{i,t}$ is not based on our assumption on the international labour division. The regression outcomes are presented in table 5 in Appendix D and fully confirm the previous results. In the first equation we find that the effect of vertical specialisation on trade elasticity is positive and significant and greater than in the original model. Including year fixed effects reduces the coefficient of the measure leaving the statistical significance unchanged at 1%. Finally, letting the coefficient of VS vary over time results in a large and significant effect on trade elasticity in 2000 and 2009, which is also significantly larger than the one recorded in the other years of the sample.

As a final robustness check, we repeat the analysis using a fourth measure of vertical specialisation that simultaneously takes into account both caveats. We consider each country's trade (export+import) in intermediates as a share of its

[33] A similar measure is used in Guerrieri and Vergara Caffarelli (2012).

total trade and we label it $IS(\text{trade})_{i,t}$. Again, the results of our analysis are fully confirmed (table 6).

5 Concluding remarks

We have analysed the effect of vertical specialisation (VS) on trade elasticity to global demand. In the model firms choose whether to adjust the extent or the intensity of VS as the demand for the final good changes. In the presence of adjustment costs we show that large shocks induce firms to adjust the VS extensive margin whereas small shocks are accommodated along the intensive margin. When, for instance, a large negative demand shock hits, firms adjust VS networks by cancelling relations (this may happen through re-nationalisation as anecdotal evidence on the recent crisis has shown). Trade elasticity is then affected since intermediate trade flows decrease proportionately more than demand.

We use recent data, a clear measure of VS and a panel framework to test this prediction. We show how the correlation between trade elasticity to world demand and VS is much higher during extraordinary times, such as the ICT-euphoria in 2000 and the 2008-09 global crisis. We also uncover a positive correlation on average.

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A Existence of the optimal adjustment thresholds

The thresholds m and M are found by equating the cost function with the adjustment of VS, $\tilde{C}(x_i)$, with the one with VS level kept at its initial(ly optimal) level $\hat{z}$, $C(x_i|\hat{z})$:

$$\tilde{C}(x_i) = C(x_i|\hat{z}) \tag{20}$$

which is

$$\nu^{\frac{1}{1+\gamma}} \left(\frac{\frac{1}{\alpha} + \delta}{\gamma} \right)^{\frac{\gamma}{1+\gamma}} (1+\gamma) x_i^{\frac{1}{1+\gamma}} = \hat{z}^{-\gamma} \nu x_i + \frac{\hat{z}}{\alpha}. \tag{21}$$

It is rather difficult to find a closed-form solution of equation (21) because the exponent $\frac{1}{1+\gamma}$ may be an irrational number. We can, however, prove that equation (21) always admits two and only two positive solutions. For this purpose it is sufficient to show that both functions are monotone and continuous and then that one lies above the other for some values, below for others and above for still others. This is enough to prove the existence of a double crossing, which gives us the thresholds m and M.

Proposition 1 *There exist two positive numbers, m and M, such that $\tilde{C}(x_i) > C(x_i|\hat{z})$ for $x_i \in (m, M)$ and $\tilde{C}(x_i) < C(x_i|\hat{z})$ for $x_i < m$ or $x_i > M$.*

Proof. Subtracting $\delta\hat{z}$ from both sides of equation (20) and rearranging we obtain:

$$\tilde{C}(x_i) - C(x_i|\hat{z}) - \delta\hat{z} = -\delta\hat{z} \tag{22}$$

Now define $G(x) = \tilde{C}(x) - (C(x|\hat{z}) + \delta\hat{z})$. Note that:

$$C(x|\hat{z}) + \delta\hat{z} = \hat{z}^{-\gamma}\nu x_i + \frac{\hat{z}}{\alpha} + \delta\hat{z} = \hat{C}(x_i, \hat{z})$$

which is one of the linear cost functions whose envelop is $\tilde{C}(x)$, specifically the one for $z_i = \hat{z}$. Consequently the function $G(x)$ is the difference between the envelop and one of its tangents. Thus $G(\cdot)$ is piece-wise monotonic and strictly concave: $G'(x) = \frac{\nu^{\frac{1}{\gamma+1}}}{1+\gamma} \left(\frac{\frac{1}{\alpha}+\delta}{\gamma} \right) x^{\frac{-\gamma}{\gamma+1}} - \hat{z}^{-\gamma}\nu \gtreqless 0$ if and only if $x \gtreqless \hat{x}$ and $G''(x) = -\nu^{\frac{1}{\gamma+1}} \left(\frac{\frac{1}{\alpha}+\delta}{(1+\gamma)^2} \right) x^{\frac{-1-2\gamma}{\gamma+1}} < 0$ for all $x > 0$. Furthermore $G(0) = -\frac{\hat{z}}{\alpha} - \delta\hat{z}$, $G(\hat{x}) = 0$ and $\lim_{x\to+\infty} G(x) = -\infty$. By the intermediate value theorem, for each interval $[0, \hat{x})$ and $[\hat{x}, +\infty)$ there exists one point (unique by piece-wise monotonicity of $G(\cdot)$) in which $G(\cdot)$ takes the value $-\delta\hat{z}$. We call these two points m and M respectively. The thesis follows by strict concavity of $G(\cdot)$. ■

B Country classification

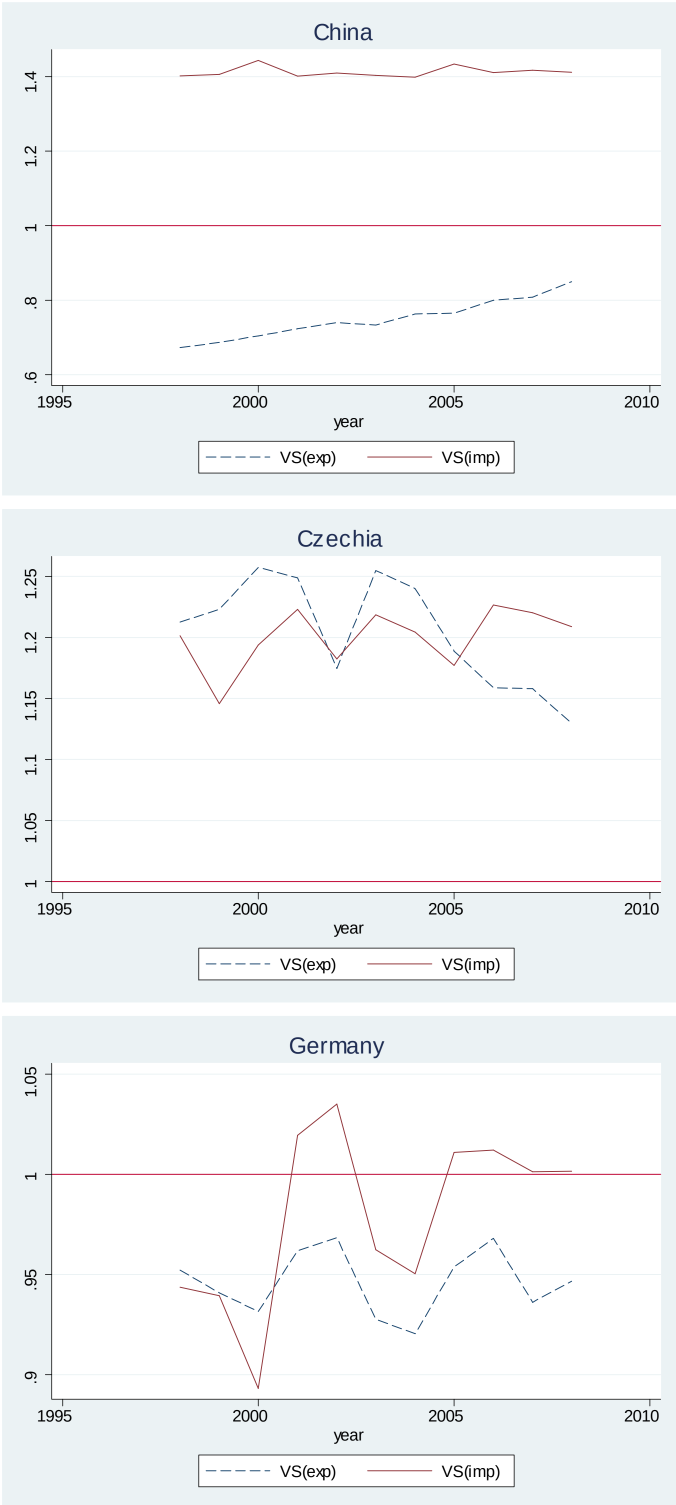
Our classification of countries is based on the World Bank's classification of economies by income, supplemented with anecdotal evidence for China, Mexico and the USA.

Final-good assembling countries are: Australia, Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, Greece, Ireland, Iceland, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Portugal, Slovenia, South Korea, Spain, Sweden, Switzerland and the UK.

Intermediate-good producing countries are: Brazil, Czech Republic, Estonia, Hungary, India, Indonesia, Poland, Russia, South Africa, Slovakia, Turkey and the USA.

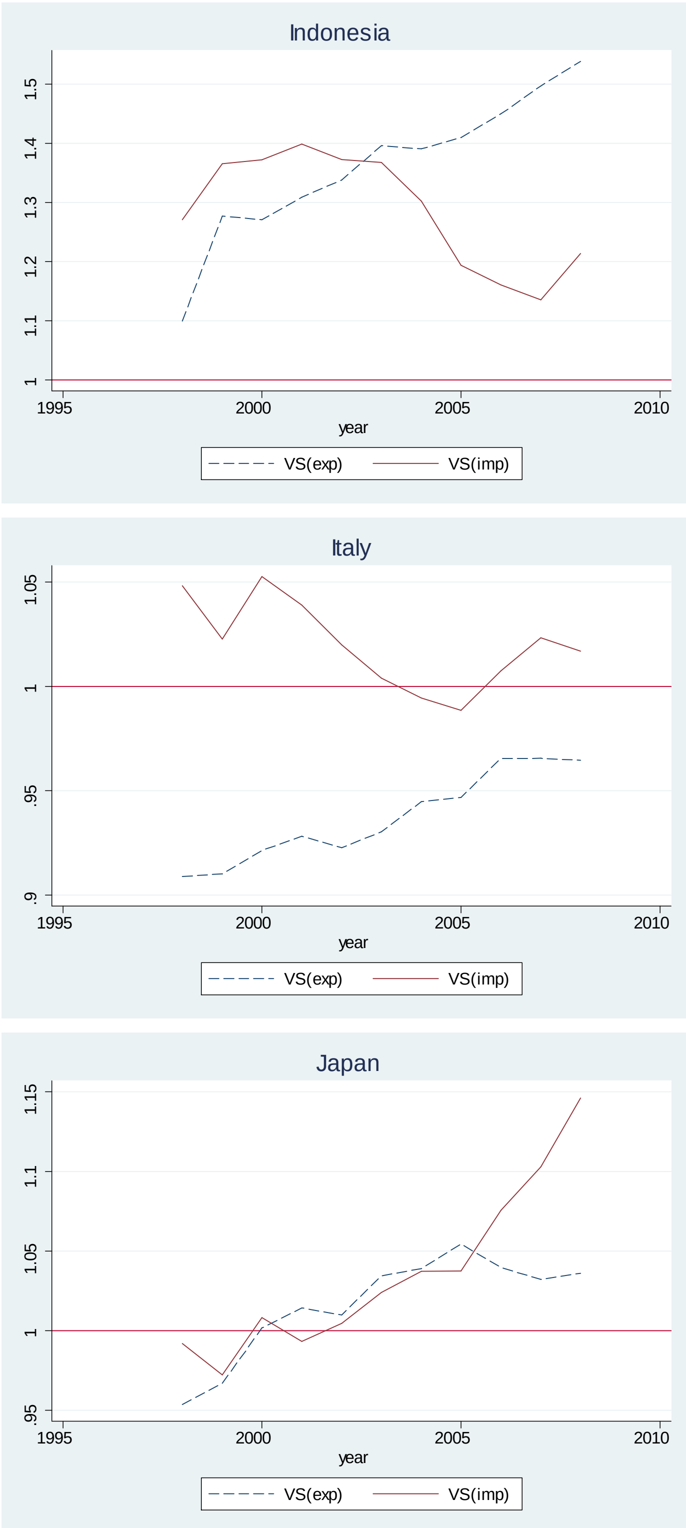
C Graphs

Figure A: Index of fragmentation



Source: Authors' calculation using UN Comtrade data.

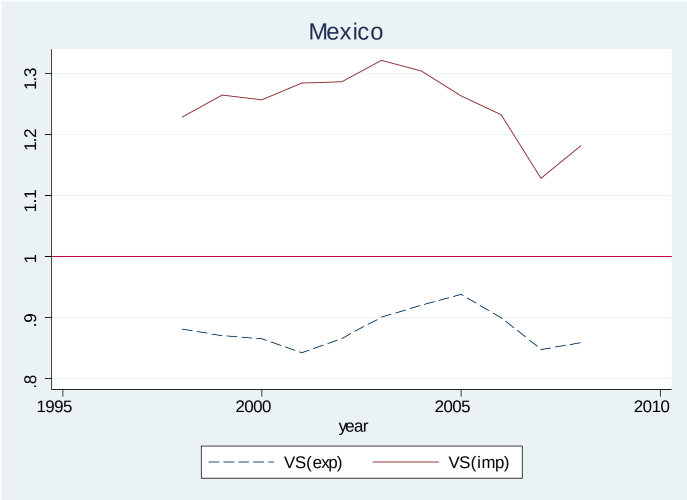
Figure A (cont.): Index of fragmentation

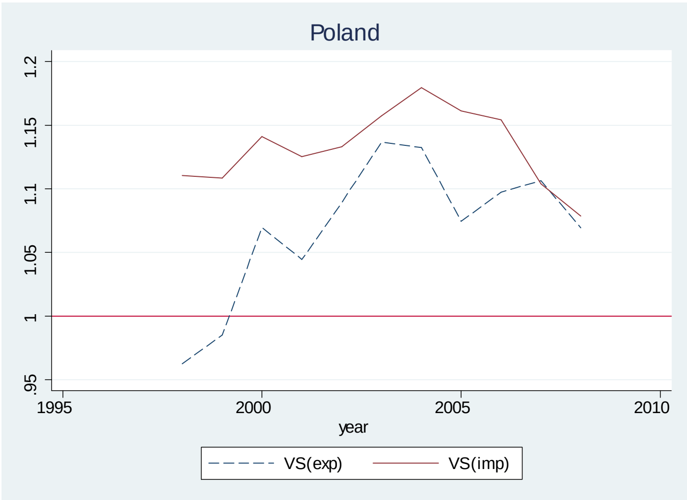


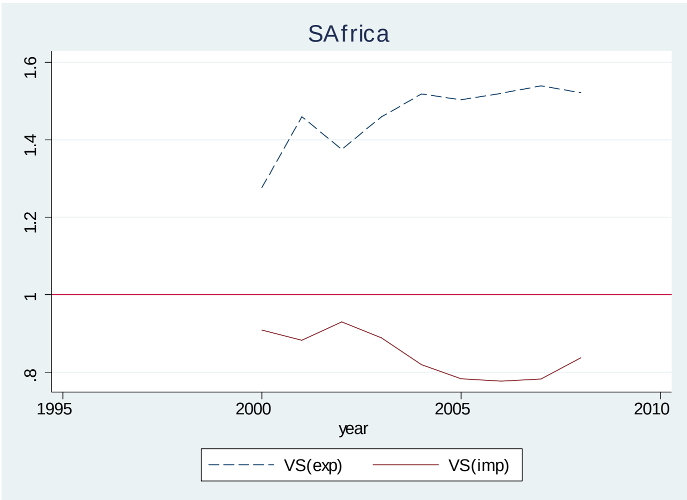
3

Source: Authors' calculation using UN Comtrade data.

Figure A (cont.): Index of fragmentation

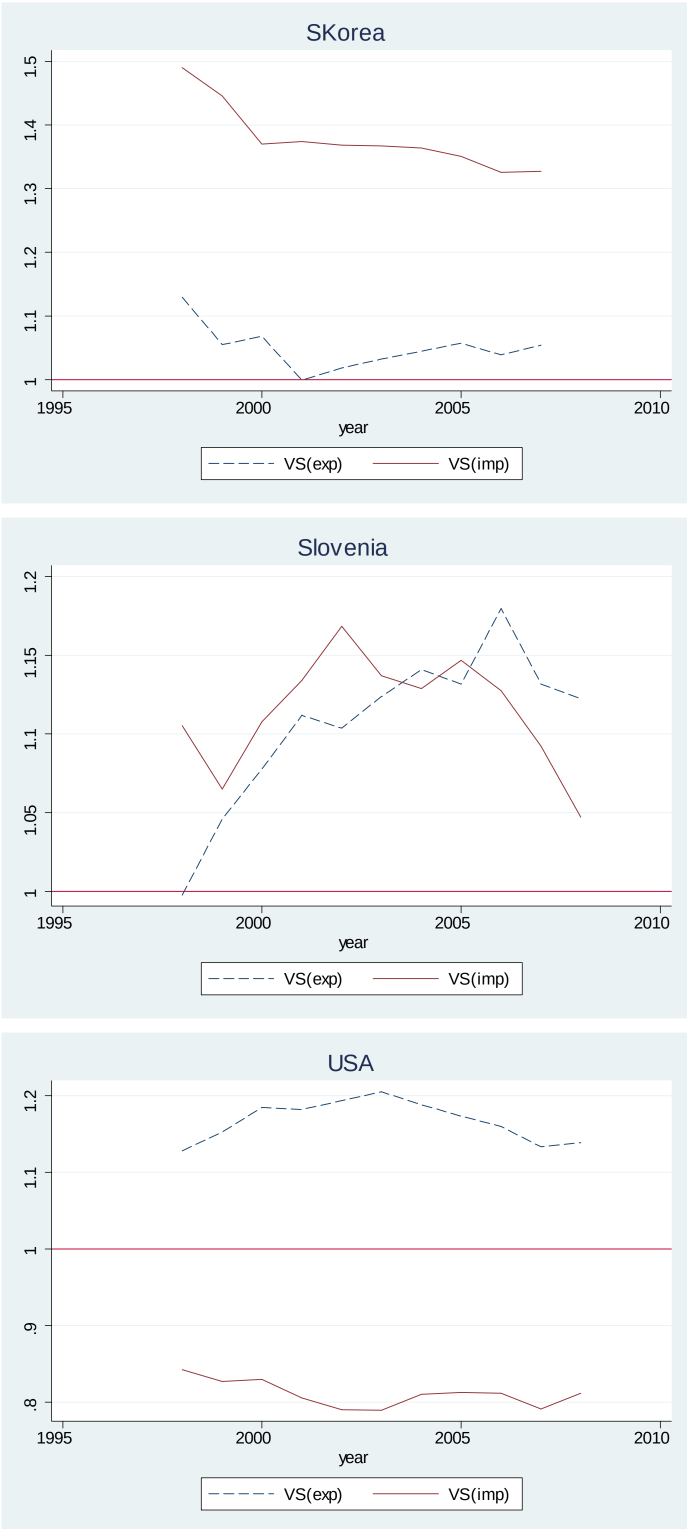






Source: Authors' calculation using UN Comtrade data.

Figure A (cont.): Index of fragmentation



Source: Authors' calculation using UN Comtrade data.

D Tables

Table 1

Summary statistics

	Obs.	Mean	St. dev.	Min	Max
Total trade	454	370,59	502.27	0.372	3390.00
GDP	532	51,03	155.15	0.003	1467.58
Trade elasticity	416	.87	1.12	-1.68	5.62
VS(imp)	412	1.03	.19	.64	1.60
VS(exp)	412	1.04	.17	.67	1.54
VS	412	1.04	.18	.69	1.54

Note: Total trade and GDP are in billions of current US dollars.

Table 2

Elasticity of trade to income (VS)

	[1]	[2]	[3]	[4]	[5]
VS(exp) × d_assembler	0.72				
	(1.42)				
VS(exp) × d_producer	2.86**				
	(1.13)				
VS(imp) × d_assembler		1.33			
		(1.30)			
VS(imp) × d_producer		0.10			
		(1.50)			
VS			2.19**	1.72**	2.75***
			(0.82)	(0.72)	(0.80)
VS × d_2008					-2.89***
					(0.15)
VS × d_2007					-1.49***
					(0.11)
VS × d_2006					-1.18***
					(0.12)
VS × d_2005					-0.66***
					(0.16)
VS × d_2004					-1.25***
					(0.13)
VS × d_2003					-1.53***
					(0.12)
VS × d_2002					-0.97***
					(0.21)
VS × d_2001					-1.99***
					(0.17)
VS × d_2000					-0.19
					(0.27)
VS × d_1999					-2.12***
					(0.22)
Num. observations	400	400	400	400	400
R^2 within	0.002	0.012	0.012	0.595	0.602
Country fixed effects	yes	yes	yes	yes	yes
Year fixed effects	no	no	no	yes	no

Note: robust standard-errors in parenthesis; ***: significant at 1%; **: significant at 5%; *: significant at 10%. The dependent variable is the elasticity of country i's trade to contemporaneous GDP of all other countries in the sample. Annual data from 1999 to 2008 and quarterly data for 2009Q1. We exclude the first and the last percentile of the dependent variable.

Table 3
Annual Partial Effects

Year	Ann. part. eff.
1999	0.630
2000	2.553***
2001	0.754
2002	1.773**
2003	1.214
2004	1.496*
2005	2.089**
2006	1.567*
2007	1.252
2008	-0.148
2009	2.746***

Note: Estimated effect of VS in listed years.***: significant at 1%; **: significant at 5%; *: significant at 10%.

Table 4

Elasticity of trade to income (IS)

	[1]	[2]	[3]	[4]	[5]
IS(exp) × d_assembler	-0.90				
	(2.96)				
IS(exp) × d_producer	5.45**				
	(2.62)				
IS(imp) × d_assembler		-1.19			
		(2.61)			
IS(imp) × d_producer		-0.60			
		(3.36)			
IS			2.35	3.62**	5.61***
			(1.79)	(1.43)	(1.58)
IS × d_2008					-5.79***
					(0.29)
IS × d_2007					-3.00***
					(0.23)
IS × d_2006					-2.35***
					(0.23)
IS × d_2005					-1.29***
					(0.32)
IS × d_2004					-2.45***
					(0.25)
IS × d_2003					-3.03***
					(0.23)
IS × d_2002					-1.93***
					(0.43)
IS × d_2001					-4.01***
					(0.35)
IS × d_2000					-0.49
					(0.53)
IS × d_1999					-4.28***
					(0.43)
Num. observations	400	400	400	400	400
R^2 within	0.001	0.010	0.004	0.596	0.602
Country fixed effects	yes	yes	yes	yes	yes
Year fixed effects	no	no	no	yes	no

Note: robust standard-errors in parenthesis; ***: significant at 1%; **: significant at 5%; *: significant at 10%. The dependent variable is the elasticity of country i's trade to contemporaneous GDP of all other countries in the sample. Annual data from 1999 to 2008 and quarterly data for 2009Q1. We exclude the first and the last percentile of the dependent variable.

Table 5

Elasticity of trade to income (VS trade)

	[3]	[4]	[5]
VS(trade)	2.99***	2.40**	3.35***
	(0.87)	(0.75)	(0.76)
VS(trade) × d_2008			-2.68***
			(0.14)
VS(trade) × d_2007			-1.36***
			(0.11)
VS(trade) × d_2006			-1.05***
			(0.12)
VS(trade) × d_2005			-0.59***
			(0.16)
VS(trade) × d_2004			-1.12***
			(0.11)
VS(trade) × d_2003			-1.36***
			(0.11)
VS(trade) × d_2002			-0.86***
			(0.18)
VS(trade) × d_2001			-1.83***
			(0.17)
VS(trade) × d_2000			-0.26
			(0.23)
VS(trade) × d_1999			-1.96***
			(0.19)
Num. observations	400	400	400
R^2 within	0.024	0.603	0.586
Country fixed effects	yes	yes	yes
Year fixed effects	no	yes	no

Note: robust standard-errors in parenthesis; ***: significant at 1%; **: significant at 5%. The dependent variable is the elasticity of country i's trade to contemporaneous GDP of all other countries in the sample. Annual data from 1999 to 2008 and quarterly data for 2009Q1. We exclude the first and the last percentile of the dependent variable.

Table 6.

Elasticity of trade to income (IS trade)

	[3]	[4]	[5]
IS(trade)	3.82**	4.82***	6.72***
	(1.73)	(1.52)	(1.52)
IS(trade) × d_2008			-5.40***
			(0.27)
IS(trade) × d_2007			-2.72***
			(0.22)
IS(trade) × d_2006			-2.10***
			(0.23)
IS(trade) × d_2005			-1.16***
			(0.32)
IS(trade) × d_2004			-2.16***
			(0.21)
IS(trade) × d_2003			-2.68***
			(0.22)
IS(trade) × d_2002			-1.70***
			(0.37)
IS(trade) × d_2001			-3.69***
			(0.34)
IS(trade) × d_2000			-0.63
			(0.45)
IS(trade) × d_1999			-4.00***
			(0.38)
Num. observations	400	400	400
R^2 within	0.011	0.604	0.586
Country fixed effects	yes	yes	yes
Year fixed effects	no	yes	no

Note: robust standard-errors in parenthesis; ***: significant at 1%; **: significant at 5%. The dependent variable is the elasticity of country i's trade to contemporaneous GDP of all other countries in the sample. Annual data from 1999 to 2008 and quarterly data for 2009Q1. We exclude the first and the last percentile of the dependent variable.

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