COMPLEXITY OF PRODUCTION PROCESSES AND THE NEED FOR PROXIMITY

Sandrine NOBLET*, Antoine BELGODERE**

Abstract - *This paper studies the effect of globalization on the geography of trade. More specifically we present the deepening integration process (i.e. the fall in transport costs) and the need for proximity as two sides of the same phenomenon. We propose a theoretical model in which both international fragmentation and increasing need for proximity in input-output relationships are endogenous responses to an exogenous fall in transport costs. Indeed, in a Dixit-Stiglitz' framework, a fall in transport costs increases the varieties of tasks making production process more complex. This increasing complexity implies that input-output linkages require a higher level of coordination. Coordination is assumed to be achieved more easily between nearby than between distant countries.*

Key-words **-** INTERNATIONAL TRADE, COMPLEXITY, PROXIMITY, TRANSPORT COSTS, COORDINATION COSTS

Classification JEL **-** F12, F15

* Université de Corse, UMR CNRS LISA 6240 ; noblet@univ-corse.fr
** Université de Corse, UMR CNRS LISA 6240 ; belgodere@univ-corse.fr

1. INTRODUCTION

Current globalization seems to exhibit two somehow paradoxical trends. The first is the increasing fragmentation of production on an international basis. International trade flows are characterized by an important share of intermediate goods or, more broadly, goods in process as documented by Ng and Yeats (2001), Hummels et al. (2001), Jones and Kierzkowski (2005) and Kimura et al. (2007) among others. According to Miroudot et al. (2009) trade in intermediates represents 56,2% of total trade for OECD countries between 1995 and 2007. The increasing fragmentation has been triggered by what Richard Baldwin called the “two great unbundlings” (Baldwin, 2006). More precisely, the fall in transport costs has weakened the need for proximity between firms and consumers and the fall in communication costs has weakened the need for proximity between upstream and downstream firms.

The second trend, that may look paradoxical with the first, is that this increasing fragmentation seems, in turn, to foster some need for geographical proximity between trade partners.

Indeed, according to Johnson and Noguera (2012), trade in intermediates has grown faster between nearby countries than between long distance partners. This echoes Hillberry and Hummels (2002) who explain home bias effect through the localized nature of intermediates trade flows suggesting that trade in intermediates is a factor of industrial concentration[1]. More recently, Baldwin and Venables (2013) argue that the need for proximity between producers can offset comparative advantages.

Thus, distance seems to count less, because production is more internationally fragmented, but distance seems to count more because more fragmented production processes are organized essentially among nearby countries. We believe both trends can be regarded as consistent with each other, if one acknowledges that more fragmented production processes are more complex, and that complexity requires proximity for coordination purposes.

Fragmentation is often associated with productivity gains[2]. However, since Kremer (1993), increasing fragmentation is also associated to an increase in complexity of production process. The underlying assumption is that the higher is the number of tasks, the higher is the risk of failure (Kremer, 1993; Costinot, 2009; Minondo and Requena-Silvente, 2013). According to Hidalgo and Hausmann (2009) the level of complexity depends on the diversity of capabilities available in a country. Finally, the complexity of production process can be linked to the nature of tasks performed. For instance, Autor et al. (2003) and Spitz (2004) have shown respectively for the United-States and Europe that there has been a switch in the nature of tasks from routine to non-routine tasks (interactive or analytical), that can be considered as more complex.

In this paper, we propose a theoretical model in which both international fragmentation and increasing need for proximity in input-output relationship are

[1]This idea has been suggested by Wolf (2000).
[2]These productivity gains are a property of Dixit-Stiglitz’ production function.

endogenous responses to an exogenous fall in transport costs. In our Dixit-Stiglitz model, based upon increasing returns to scale technology, a fall in transport costs may increase the international division of labour. The increasing international division of labour can be interpreted as increasing specialization of intermediate goods. As a consequence, we assume that production processes become more complex, which, in turn, implies that input-output linkages require a higher level of coordination. Coordination is assumed to be achieved more easily between nearby than between distant countries. As a result, trade increases with all partners, but more quickly for nearby than for distant countries.

Hence, our paper adds to the recent literature on complexity. Hidalgo and Haussmann (2009) use the concept of complexity in order to explain growth differential between high wage and low wage countries. Minondo and Requena-Silvente (2013) show that the level of complexity was able to predict the structure of trade flows. Finally this link between complexity and international trade has also been studied through the quality of institutions. Berkowitz et al. (2006) show that institutional quality matters more for trade in complex goods than in simple ones since the level of contract incompleteness is higher for complex goods. Some other papers have emphasized the importance of institutional quality for trade in differentiated goods (Levchenko, 2007; Nunn, 2007; Ranjan and Lee, 2007; Feenstra et al., 2013).

The remainder of the paper is organized as follows: section 2 presents a micro model of coordination costs, section 3 introduces this micro model in a general equilibrium model of international trade, section 4 shows the unambiguous effect of the fall in transport costs regarding to the geography of trade. Section 5 provides a discussion of our result and the last section concludes.

2. COMPLEXITY IN INPUT-OUTPUT LINKAGES

Here, we consider production processes that consist of assembling a continuum of intermediate goods of mass N. A specific intermediate good can be used only if its characteristics fit perfectly with the characteristics of all the other intermediate goods. The final good producer both assembles the intermediate goods, and coordinates the various intermediate producers in a bid to avoid any mismatch among them. This coordination activity requires proximity, so the probability that a given intermediate good fits with another one is a decreasing function of geographical distance (d) between the intermediate and the final good producers. We assume this probability is given by $1/(1+\phi d)$ (with $\phi > 0$), which is equal to 1 when $d = 0$, and tends toward 0 for infinite distance. Since an intermediate good must fit not only with one other good but also with all the others that are part of the production process, the probability it can be used is $1/(1+\phi d)^N$ (this modelling isinspired by Michael Kremer's O'ring theory (Kremer, 1993). It follows then, that a risk-neutral final good producer must buy a quantity $x(1+\phi d)^N$ of an intermediate good in order to use an expected value of x. A more realistic interpretation is that the final good producer can buy an insurance contract (or equivalently add a clause to its contract with the supplier) that guarantees free replacement of the intermediate good should it not incorporate the appropriate characteristics. If p is the price of this intermediate good, then the price of the insurance contract would be $p((1+\phi d)^N - 1)$. In what follows, we refer to this insurance price as the "coordination cost" (as in Noblet, 2011), although it is more accurately the cost of lack of coordination in input-output relations.

In addition to this coordination cost, downstream firms have to bear transport costs. We assume that the transport cost is an iceberg cost, which increases the cost by $p\theta d$, where $\theta > 0$ is a parameter that denotes the transport technology. This means that a fall in transport costs is modelled as a fall in θ.

Finally, the expected cost of using one unit of the intermediate good is given by the following expression:

$$p(1+\theta d)(1+\phi d)^N \tag{1}$$

This equation provides some insight for the point we want to make in this paper. Modern models of international trade based on a Dixit-Stiglitz framework exhibit an increasing variety of goods. Here, an increasing integration corresponds to a fall in θ, whereas an increasing variety of goods corresponds to an increase in N. Let us assume a final good producer has both short-distance and long-distance trading partners. If a fall in θ is accompanied by an increase in N, then the non-linearity of expression 1 implies that the global transfer costs for both types of partners does not evolve proportionally. In those conditions, the impact of integration on the shape of international trade depends crucially on two things: the parameter ϕ, and the importance of the increase in N in response to the fall in θ. In other words, globalization can strengthen the impact of distance on trade if this globalization increases the complexity of production processes, and if distance matters for the coordination of intermediate good suppliers.

We address these issues in the next two sections by plugging the model of coordination costs summarized by relation 1 into an international trade model.

3. INTERNATIONAL TRADE

In this section and section 4, we study an international trade model where firms support a coordination cost as previously defined. This section presents the structure of our model, while section 3 discusses the implications of our model in terms of distance of trade.

The model is a symmetric multi-country model. In order to simplify the notations, we do not use country-specific subscripts.

3.1. Consumers

In each country, a representative consumer has a utility function given by $U(x_A, X) = \left(x_A^{\frac{\sigma-1}{\sigma}} + X^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$, where x_A and X are the quantities of agricultural good and (final) industrial good that are consumed, and $\sigma > 1$ is the elasticity of substitution between both goods. The agricultural good is chosen as the *numeraire*, and P is the price of the industrial good. The budget constraint is

$y = x_A + PX$ where y is the national income. Utility maximization results in the following demand functions:

$$x_A = \frac{y}{1 + P^{1-\sigma}} \tag{2}$$

$$X = \frac{y}{P + P^{\sigma}} \tag{3}$$

3.2. Agricultural sector

In each country, a representative firm produces the agricultural good out of labour, with constant returns to scale:

$$x_A = AL_A \tag{4}$$

where L_A is the quantity of labour employed in the sector, and $A > 0$ is a productivity parameter. The profit in the sector can be written as $AL_A - \omega L_A$, where ω is the wage rate. Since this sector is competitive, the equilibrium wage rate is simply:

$$\omega = A \tag{5}$$

and the profit is nil at equilibrium.

3.3. Industrial downstream sector

In each country, a representative firm builds a final industrial good out of intermediate goods, with a CES production function $X = \left[\int_0^N x_i^{(\sigma-1)/\sigma}\, di\right]^{\sigma/(\sigma-1)}$, where x_i is the quantity of intermediate good of variety i. Intermediate goods can be bought locally or from foreign countries. The production cost can be written as $\int_0^N \tau_i\, x_i p_i di$, where p_i is the price of variety i and τ_i is the transfer cost of variety i. Following the modeling presented in section 1, we define τ_i as:

$$\tau_i = (1 + \theta d_i)(1 + \phi d_i)^N \tag{6}$$

Minimizing this cost for a given production results in the following demand:

$$x_i = (\tau_i p_i)^{-\sigma} c^{\sigma} X \tag{7}$$

where $c \equiv \left[\int_0^N \left(\tau_j p_j\right)^{1-\sigma} dj\right]^{1/(1-\sigma)}$

Replacing the optimal value of x_i in the definition of production cost, gives the cost function $COST(X) = cX$. Since the final good sector is competitive, the equilibrium price equates to the marginal cost:

$$P = c \tag{8}$$

3.4. Industrial upstream sector

The industry upstream sector is characterized by monopolistic competition. Each firm supplies both local and foreign downstream firms. Let p be the price imposed by a typical firm in this sector. Downstream firms in different locations do not face the same transfer costs, but, according to equation 7, their individual demand for a typical variety is always: $constant \times p^{-\sigma}$. It follows that $-\sigma$ is the price-elasticity of aggregate demand.

Technology in this sector exhibits increasing returns to scale. A typical firm hires a quantity L_x of labour, and produces a quantity $x = L_x - f$ of output, where $f > 0$ is a fixed requirement. It follows that the marginal cost is simply ω. Thus, each firm applies the standard pricing:

$$p = \omega \frac{\sigma}{\sigma - 1} \tag{9}$$

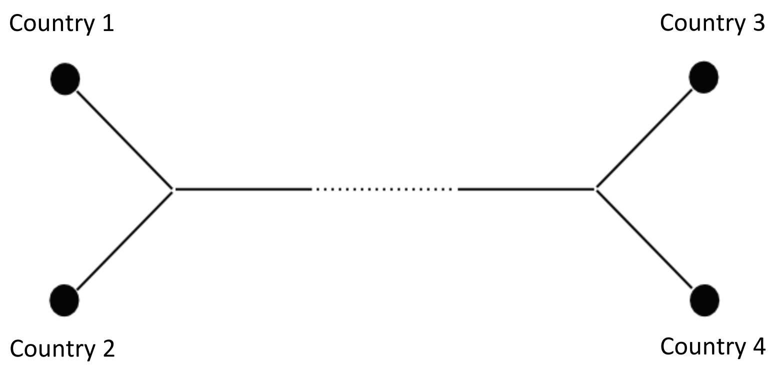
At equilibrium, the classical no-profit condition applies:

$$x = f(\sigma - 1) \tag{10}$$

3.5. Physical geography

This model needs to include more than two countries, so that we can compare trade between neighbours with trade between distant partners. We also need to respect a perfect symmetry between countries, in order to keep the model as tractable as possible. The simplest way to fulfil these conditions is to assume the four-country world depicted in figure 1, where the lines represent the roads between the countries.

Figure 1. The 4-country world



Let $\underline{d}(> 0)$ be the distance between neighbours, and $\bar{d}(> \underline{d})$ the distance between distant partners. Here, perfect symmetry prevails, because each country has one neighbour and two distant partners.

Under these assumptions, we can define three different levels of transfer costs:

$$\tau_i = 1 \text{ for local trade}$$

$$\tau_i = \underline{\tau} \equiv (1 + \theta\underline{d})(1 + \phi\underline{d})^N \text{ for trade between neighbours} \tag{11}$$

$$\tau_i = \bar{\tau} \equiv (1 + \theta\bar{d})(1 + \phi\bar{d})^N \text{ for trade between distant partners}$$

Perfect symmetry implies that $N/4$ varieties are produced in each country. Thus, the price of the final industrial good, given by equation 8, can be written as:

$$\begin{aligned} P &= \left[\frac{N}{4}\left(\frac{\omega\sigma}{\sigma-1}\right)^{1-\sigma} + \frac{N}{4}\left(\frac{\omega\sigma}{\sigma-1}\right)^{1-\sigma} \underline{\tau}^{1-\sigma} + \frac{N}{2}\left(\frac{\omega\sigma}{\sigma-1}\right)^{1-\sigma} \bar{\tau}^{1-\sigma}\right]^{1/(1-\sigma)} \\ &= \left(\frac{N}{4}\right)^{1/(1-\sigma)} \left(\frac{\omega\sigma}{\sigma-1}\right) \left(1+\underline{\tau}^{1-\sigma}+2\bar{\tau}^{1-\sigma}\right)^{1/(1-\sigma)} \end{aligned} \tag{12}$$

Demand for intermediate goods defined in equation 7 also has three different values:

$$\begin{aligned} &x_i = x^0 \equiv \left(\frac{\omega\sigma}{\sigma-1}\right)^{-\sigma} P^\sigma X \text{ for local trade} \\ &x_i = \underline{x} \equiv x^0 \underline{\tau}^{-\sigma} \text{ for trade between neighbours} \\ &x_i = \bar{x} \equiv x^0 \bar{\tau}^{-\sigma} \text{ for trade between distant partners} \end{aligned} \tag{13}$$

3.6. Closing the model

There are three more equations required to solve the model. The first clearing condition concerns the labour market. Let L be the each country's total labour force. This labour force is used by the upstream industry sector and the agriculture sector:

$$\frac{N}{4} L_X + L_A = L \tag{14}$$

The second clearing condition relates to the intermediate good market. In this market, each firm supplies x and faces four demands: x^0 from the local market; $\underline{x}$ from the neighbouring country; and $\bar{x}$ from each of the two distant countries. However, when foreign downstream firms want to use $\underline{x}$ and $\bar{x}$, they must purchase $\underline{x\tau}$ and $\bar{x}\bar{\tau}$ to compensate for the transport and coordination losses. Thus, at equilibrium (using equation feq:x):

$$x = x^0\left(1+\underline{\tau}^{1-\sigma}+2\bar{\tau}^{1-\sigma}\right) \tag{15}$$

The third one is the definition of national income, which is simply the workers' income since the profit is nil in the three sectors:

$$y = wL \tag{16}$$

3.7. Summarizing, simplifying

The model presented in this section can be expressed in a quite tractable way, although it has no analytical solution.

Four variables have trivial solutions: $\omega = A$, $y = AL$, $p = \frac{A\sigma}{\sigma-1}$ and $x = f(\sigma-1)$. Using those values reduces the model to a 11-equation 11-variable system. Variables are: L_A, L_x, x_A, X, P, N, $\underline{\tau}$, $\bar{\tau}$, x^0, $\underline{x}$ and $\bar{x}$. Equations are:

$$L_A = x_A/A \tag{17}$$

$$\frac{N}{4}L_x + L_A = L \tag{18}$$

$$x_A = \frac{AL}{1+P^{1-\sigma}} \tag{19}$$

$$X = \frac{AL}{P+P^{\sigma}} \tag{20}$$

$$x^0 = X\left(\frac{A\sigma}{\sigma-1}\right)^{-\sigma} P^{\sigma} \tag{21}$$

$$\underline{x} = x^0 \underline{\tau}^{-\sigma} \tag{22}$$

$$\bar{x} = x^0 \bar{\tau}^{-\sigma} \tag{23}$$

$$P = \left(\frac{N}{4}\right)^{1/(1-\sigma)} \left(\frac{A\sigma}{\sigma-1}\right)\left(1+\underline{\tau}^{1-\sigma}+2\bar{\tau}^{1-\sigma}\right)^{1/(1-\sigma)} \tag{24}$$

$$x^0 = \frac{f(\sigma-1)}{1+\underline{\tau}^{1-\sigma}+2\bar{\tau}^{1-\sigma}} \tag{25}$$

$$\underline{\tau} = \left(1+\theta\underline{d}\right)\left(1+\phi\underline{d}\right)^N \tag{26}$$

$$\bar{\tau} = \left(1+\theta\bar{d}\right)\left(1+\phi\bar{d}\right)^N \tag{27}$$

Variables $\underline{\tau}$, $\bar{\tau}$, P, x_A, X, L_A and L_x can easily be expressed as a function of the parameters and N[3], whereas $\underline{x}$ and $\bar{x}$ can be expressed as a function of the parameters, N and x^0 [4]. This leaves a system of two variables, x^0 and N, and two equations, 21 and 25. By removing x^0 from these equations, we get:

$$\frac{[A\sigma/(\sigma-1)]^{\sigma-1}}{1+\left[\left(1+\theta\underline{d}\right)\left(1+\phi\underline{d}\right)^N\right]^{1-\sigma}+2\left[\left(1+\theta\bar{d}\right)\left(1+\phi\bar{d}\right)^N\right]^{1-\sigma}} = \frac{L}{f\sigma}-\frac{N}{4} \tag{28}$$

Equation 28 is the cornerstone of the model, because solving this equation would allow us to solve the entire model. Although equation 28 is clearly not solvable, it provides an interesting insight into the ambiguous effect of a fall in transport costs on the geography of trade, which is discussed in the next section.

[3]By using equations 26, 27, 24, 19, 20, 17 and 18, in this order.
[4]By using equations 22 and 23.

4.THE GEOGRAPHY OF TRADE

We focus here on the impact of a fall in θ, the pure transport cost, on the ratio $\frac{\underline{x}}{\overline{x}}$, namely the ratio of neighbour to distant exchanges. This fall in transport costs strengthens the importance of distance if this ratio increases when θ decreases. Notice that, according to equations 22 and 23, $\frac{\underline{x}}{\overline{x}} = \left(\frac{\overline{\tau}}{\underline{\tau}}\right)^{\sigma}$, so we can focus alternatively on the ratio of both transfer costs:

$$\frac{\overline{\tau}}{\underline{\tau}} = \left(\frac{1+\theta\overline{d}}{1+\theta\underline{d}}\right)\left(\frac{1+\phi\overline{d}}{1+\phi\underline{d}}\right)^{N} \tag{29}$$

The right-hand side (RHS) of equation 29 highlights the two opposite forces in globalization: the fall in transport costs (θ) clearly increases $\left(\frac{1+\theta\overline{d}}{1+\theta\underline{d}}\right)$ (since $\underline{d} < \overline{d}$), which is the transport cost ratio, whereas increased complexity, measured by an increase in N, clearly decreases $\left(\frac{1+\phi\overline{d}}{1+\phi\underline{d}}\right)^{N}$, which is the coordination cost ratio. Two points matter in order to know whether distance will have more or less importance as a result of globalization: 1) the impact of changes in θ on N; 2) the size of ϕ. Obviously, if the fall in θ has only a small impact on N, then the transport cost effect is likely to outdo the coordination cost effect. The same applies if ϕ is very small, *ie.* if the probability of mismatch for distant produced intermediate goods is low[5].

Formally, the derivative of the log of expression 29 with respect to θ is written as:

$$\frac{\partial log(\overline{\tau}/\underline{\tau})}{\partial\theta} = \frac{\overline{d}-\underline{d}}{(1+\theta\underline{d})(1+\theta\underline{d})} + \frac{\partial N}{\partial\theta}\left[log(1+\phi\overline{d}) - log(1+\phi\underline{d})\right] \tag{30}$$

where $\frac{\partial N}{\partial\theta}$ is the reaction of the number of varieties to an increase in the transport costs in the model presented in section 2. The direct effect (the transport cost effect) is measured by $\frac{\overline{d}-\underline{d}}{(1+\theta\underline{d})(1+\theta\underline{d})}$, which is clearly positive. The indirect effect is measured by $\frac{\partial N}{\partial\theta}\left[log(1+\phi\overline{d}) - log(1+\phi\underline{d})\right]$, which clearly has the same sign as $\frac{\partial N}{\partial\theta}$, which, as we will see, is negative.

Distance becomes more important when transport costs fall if expression 30 is negative, which requires:

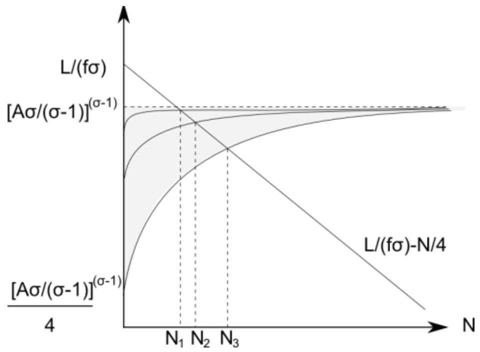
$$\frac{\partial N}{\partial\theta} < \frac{\overline{d}-\underline{d}}{(1+\theta\underline{d})(1+\theta\underline{d})\left[log(1+\phi\overline{d}) - log(1+\phi\underline{d})\right]} (< 0) \tag{31}$$

The impact of θ on N can be depicted using equation 28. In figure 2, where the decreasing line represents the RHS of equation 28, whereas the three increasing curves represent the left-hand-side (LHS), for three different values of θ. The grey area represents all the possible locations for the curve representing

[5] If $\phi = 0$, the coordination cost ratio reduces to 1^N.

the LHS, for values of θ ranging from 0 to ∞. Whatever the value of θ, this curve tends asymptotically toward $[A\sigma/(\sigma-1)]^{\sigma-1}$ when $N \to \infty$. When $\theta = 0$, the curve starts from $\frac{[A\sigma/(\sigma-1)]^{\sigma-1}}{4}$ (for $N = 0$) then converges toward $[A\sigma/(\sigma-1)]^{\sigma-1}$. When $\theta \to \infty$, the curve tends toward the dashed horizontal line.

Figure 2. Determination of N, for 3 different values of θ



The mechanism behind this increase in N is quite simple: a fall in θ decreases the price P of the final industrial good (see equation 24). Since σ, the elasticity of substitution between both types of consumption goods is higherthan 1, the fall in P results in an increase in the expenditure in industrial goods. This expenditure is equal to the expenditure on intermediate goods, because they are the only input to final good production and the returns to scale are constant. This increase in demand results in an increase in N, because x and p are constant.

In order to know whether the impact of θ on N is large enough to fulfil condition 31, we need an analytical expression of this impact. Applying implicit functions theorem to equation 28 gives:

$$\frac{\partial N}{\partial \theta} = \frac{4p^{\sigma-1}(1-\sigma)\left(\underline{d}\left(1+\phi\underline{d}\right)\tau^{-\sigma} + 2\overline{d}\left(1+\phi\overline{d}\right)\overline{\tau}^{-\sigma}\right)}{B^2 - 4p^{\sigma-1}(1-\sigma)\left(log\left(1+\phi\underline{d}\right)\underline{\tau}^{1-\sigma} + 2log\left(1+\phi\overline{d}\right)\overline{\tau}^{1-\sigma}\right)} \tag{32}$$

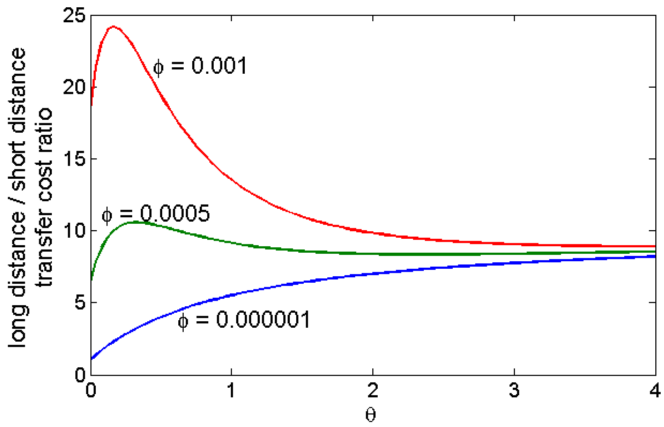
where p, $\underline{\tau}$ and $\overline{\tau}$ are defined as in equations 9, 26 and 27, and $B \equiv 1 + \underline{\tau}^{1-\sigma} + 2\tau^{1-\sigma}$.

Proving that a fall in transport costs *can* strengthen the impact of distance on trade requires us to show that equation 32 can be compatible with condition 31. Although the complexity of equation 32 does not allow for an analytical proof, it can be used to show numerically that, for some sets of parameters, this outcome can occur.

For instance, with the parameters $\underline{d} = 1$, $\overline{d} = 10$, $\sigma = 4$, $\theta = 1$, $A = 5$, $f = 1$, $L = \sigma f(A\sigma/(\sigma-1))^{\sigma-1}$ and $\phi = 0.000001$, it can be computed that $N = 133.0403$ is the solution to equation 28. We use equation 32 to calculate $\frac{\partial N}{\partial \theta} = -178.8048$. The direct effect of a change in θ is $\frac{\overline{d}-\underline{d}}{(1+\theta\underline{d})(1+\theta\underline{d})} = 0.409$, while the indirect effect is $\frac{\partial N}{\partial \theta}\left[log\left(1+\phi\overline{d}\right) - log\left(1+\phi\underline{d}\right)\right] = -0.0016$. Thus, here, the net effect is clearly positive: a fall in θ decreases the importance of distance in trade. The very small value of ϕ gives a very small weight to the coordination cost ratio. In contrast, for $\phi = 0.001$, the other parameters remaining unchanged, we get: $N = 100.4212$ and $\frac{\partial N}{\partial \theta} = -107.9839$. Here, the direct effect is still 0.409 (note that neither N nor ϕ has an impact on the direct effect), whereas the indirect effect is -0.9665 which makes the net effect negative $-0.409 - 0.9665 = 0.5575$.

Figure 3 depicts the ratio $\frac{\bar{\tau}}{\underline{\tau}}$ as a function of θ, for three values of ϕ: a small value ($\phi = 0.000001$); an intermediate value ($\phi = 0.005$) and a high value ($\phi = 0.001$). Here, the impact of ϕ is clear: when uncertainty is low in the input-output relationship (low ϕ), a fall in transport costs lowers the importance of distance. When uncertainty is important (high ϕ), a fall in transport costs has a non-monotonic impact on the importance of distance. At some stages, the increased complexity of the production processes *can* result in an increased need for proximity. In the most extreme case ($\phi = 0.001$), distance matters more for nil than for infinite transport costs.

Figure 3. The ratio $\frac{\bar{\tau}}{\underline{\tau}}$ as function of θ



5. DISCUSSION

In this paper we argued that the increasing complexity of the production process, triggered by a fall in transport costs, strengthens the need for proximity between downstream firms and their suppliers. Consequently, a fall in transport costs leads to an overall increase in trade, but can make short distance trade increase more rapidly than long distance. Now, we want to discuss several empirical implications of our model.

Our model could be interpreted in light of Baldwin's two unbundlings[6] framework. This framework distinguishes the first unbundling triggered by a fall in transport costs, from the second unbundling triggered by a fall in com-

[6]Baldwin (2006).

munication and coordination costs. The first allows firms to be located at a distance from their customers, the second (currently happening), allows different tasks in the production process to be located apart from each other. Clearly, in our model the first unbundling corresponds to an exogenous fall in θ. However, regarding the second unbundling, things are more complicated. At first sight, it seems that the second unbundling could be modelled as an exogenous fall in ϕ, but in our model, the first unbundling endogenously increases coordination costs through an increase in N, which tends to limit the second undbundling (recall that the coordination costs coefficient is given by $(1 + \phi d)^N$). This effect recalls the Kremer's O'ring theory since it underlines the importance of the number of tasks. An empirical implication is that the second unbundling would be delayed with respect to the improvement in communication technologies.

Another empirical implication of our model is production processes should be more complex today than a few decades ago. Let us present some evidences. Spitz (2004) shows that an important feature of the fragmentation of production processes is the decreasing share of routine tasks performed by workers, whatever their skill level. More precisely, among these non-routine tasks, he highlights a particular increase in interactive tasks. In our view, this switch from routine to non-routine and interactive tasks might reflect the increasing complexity of production processes. Also, Minondo and Requena-Silvente (2013) show that the division of labour between Northern and Southern countries is related more to the level of complexity than factor intensity. These previous works allow us to interpret the increasing complexity of the production process as a consequence of the increasing share of non-routine tasks in production, which require greater coordination and proximity.

If the complexity of the production process increases the need for proximity, then we should observe that the distances in trade of intermediate goods are shorter than the distances involved in trade in final goods. Indeed, this point is suggested by Wolf (2000) and emphasized by Hilleberry and Hummels (2002) as mentioned in introduction.

Finally, our results echoes the so called *distance puzzle* literature. This distance puzzle has been widely discussed in the literature since Leamer and Medburry (1993) first drew attention to it. The puzzle is that "the world is not getting smaller": distance still matters in trade, despite declining trade costs. Most studies based on gravity equations show increasing or constant distance coefficients (see among others Leamer and Medberry, 1993; Brun et al., 2005; Disdier and Head, 2008; Berthelon and Freund, 2008), and decreasing or constant trends for distance of trade (DOT) (Carrère and Schiff, 2005; Berthelon and Freund, 2008). Our model suggests that it should be tested for the most complex goods.

6. CONCLUDING REMARKS

Our goal in this paper was to bring together several features of the current globalization process generally considered important by the international trade literature: (i) the importance of trade in intermediate goods, which reflects a switch in specialization from a sectoral to a task basis (Grossman and Rossi-

Hansberg, 2006); (ii) the emergence of production processes coordinated on a regional scale, which leads to distinguish short-distance (regional trade) from long-distance trade (inter-continental trade) (Hilleberry and Hummels, 2002); (iii) the increasing complexity of production processes, which corresponds to a deepening of the division of labour (Krugman, 1995)[7]; (iv) the need to distinguish between improvements in transport technology and improvements in communication-coordination technology (Baldwin, 2006); and (v) the importance of coordinating complexifying production processes, which echoes Kremer's intuition that the number of task increases the probability of failure (Kremer, 1993).

In doing so, we presented a model that exhibits endogenous increase in coordination costs as a consequence of a fall in transport costs, via an increase in the number of tasks. Although the empirical implications of this model seem supported by several contributions, as discussed in section 5, a robust test of this model would require a relevant measure of complexity, in order to check if: (i) production processes are becoming more complex, (ii) complexity increases the need for geographical proximity between downstream firms and their suppliers. We would expect future work to perform those tests would prove fruitful.

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COMPLEXITÉ DES PROCESSUS DE PRODUCTION ET BESOIN DE PROXIMITÉ

Résumé - *Cet article étudie les effets de la globalisation sur la géographie des flux commerciaux. Plus précisément, nous présentons l'approfondissement du processus d'intégration (à savoir la baisse des coûts de transport) et le besoin de proximité comme les deux faces d'un même phénomène. Nous proposons un modèle théorique dans lequel la fragmentation et le besoin de proximité dans les liens input-output sont endogènes à la baisse des coûts de transport. En effet, dans un cadre à la Dixit-Stiglitz, la baisse des coûts de transport entraîne une augmentation du nombre de variétés de biens intermédiaires – ou tâches – rendant les processus de production plus complexes. Cette complexification implique une augmentation du besoin de coordination dans les relations input-output. La coordination est supposée être plus facile à réaliser entre pays voisins qu'entre pays lointains.*

Mots-clés - COMPLEXITÉ, PROXIMITÉ, COÛTS DE TRANSPORT, COÛTS DE COORDINATION ET COMMERCE INTERNATIONAL