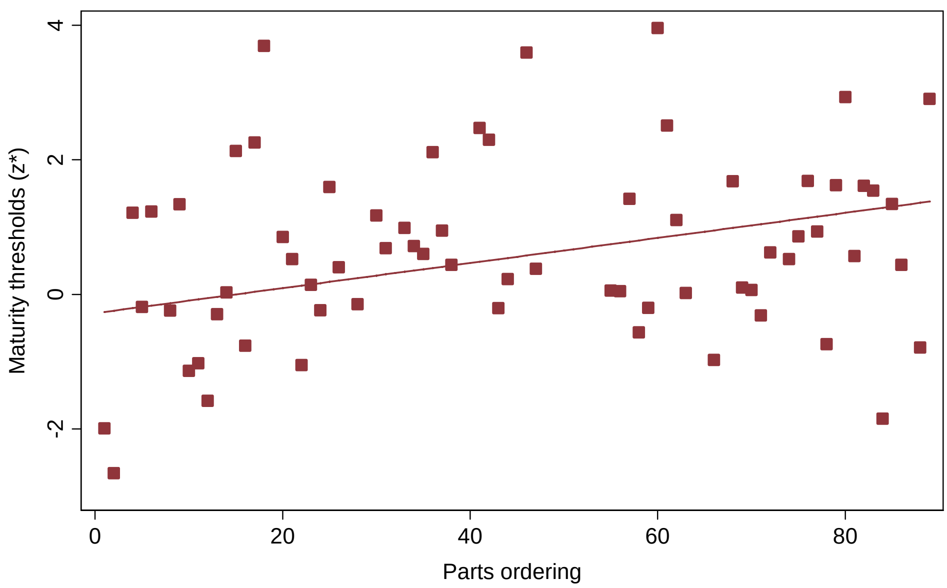
Appendix II Empirical illustration: parts ordering & estimates

We have used two alternative methods to establish a universal ordering of parts. The one developed by Feenstra and Rose (2000) starts from the order in which each country is observed starting to export each part to the United States. For a balanced panel, we could simply average across all country-specific orderings to obtain a universal ranking. However, not all countries are observed eventually exporting all parts. To overcome this missing data problem, the authors propose an iterative regression procedure that modifies the observed country-specific rankings before averaging them. It has attractive properties under the maintained assumption that missing observations for each country are ranked before or after the observed parts. The procedure shifts the ranking over the subset of observed parts up by a country-specific factor to minimize the sum of squared deviations from the universal ranking. This can be accomplished in a non-parametric regression framework with a weight on each country to reflect the number of observations. The procedure is repeated until the universal ranking has converged.

The alternative method by Audretsch, Sanders, and Zhang (2012) fits the evolution of (log) total U.S. imports with a quadratic time trend. Separate regressions for each part invariably generate a fitted curve with a concave profile after controlling for aggregate U.S. automotive parts imports. The maturity of each part in each year is then given by its place on the curve as measured by the time derivative which turns from positive to negative as time progresses. The same maturity is applied to all countries. A feature of this approach is that the ranking of parts does not need to be constant over time. In Figure A.1 we illustrate that the positive relationship between the z^* proxy and the parts ordering for India from Figure 4, obtained using the Feenstra and Rose (2000) method, also appears using the alternative method to rank parts.

Figure A.1 Sourcing thresholds for successive intermediates imported from India using the Audretsch et al. (2012) method to rank parts



Finally, in Table A.1 we list the slopes from regressions of the maturity proxy on the parts ordering for the 20 most important automotive component importers into the United States. Each coefficient comes from a separate OLS regression, one for each country and ranking method to establish the parts ordering. While we have estimated these regressions for all 54 countries in the sample, many coefficients become insignificant for smaller countries that export only a few parts. Still, the vast majority of coefficients are estimated to be positive, especially for developing countries.

Table A.1 Relationship between the maturity proxy and the parts ordering (Top 20 importers; separate regressions by country)

Parts ordering:	Feenstra & Rose (2000)		Audretsch *et al.* (2012)	
	Coef.	(t-stat)	Coef.	(t-stat)
Canada	-0.007**	(2.01)	-0.005*	(1.68)
Mexico	-0.001	(0.19)	0.002	(0.36)
China	0.012***	(2.85)	0.009*	(1.89)
South Korea	0.005	(1.15)	0.011**	(2.40)
France	0.010***	(2.85)	-0.002	(0.70)
Taiwan	0.016***	(3.37)	0.006**	(1.65)
Brazil	-0.001	(0.01)	-0.005	(1.17)
Italy	0.008**	(2.12)	0.008**	(2.17)
India	0.012**	(2.42)	0.011**	(2.46)
Spain	0.010**	(1.98)	-0.009	(1.49)
Sweden	0.005	(1.46)	0.004	(0.98)
Thailand	0.006	(0.76)	-0.005	(0.69)
Australia	0.010**	(1.90)	0.004	(0.76)
South Africa	0.008*	(1.68)	0.012*	(1.84)
Venezuela	0.014**	(2.23)	0.006	(0.67)
Switzerland	0.009**	(2.07)	-0.011**	(2.06)
Indonesia	0.023**	(2.39)	0.014*	(1.90)
Argentina	0.023***	(5.15)	0.022***	(3.60)
Turkey	0.029***	(5.71)	0.006	(1.10)
Poland	0.017***	(2.69)	0.013**	(1.95)

Note: ***, **, * indicate coefficients significant at the 1%, 5%, 10% level.

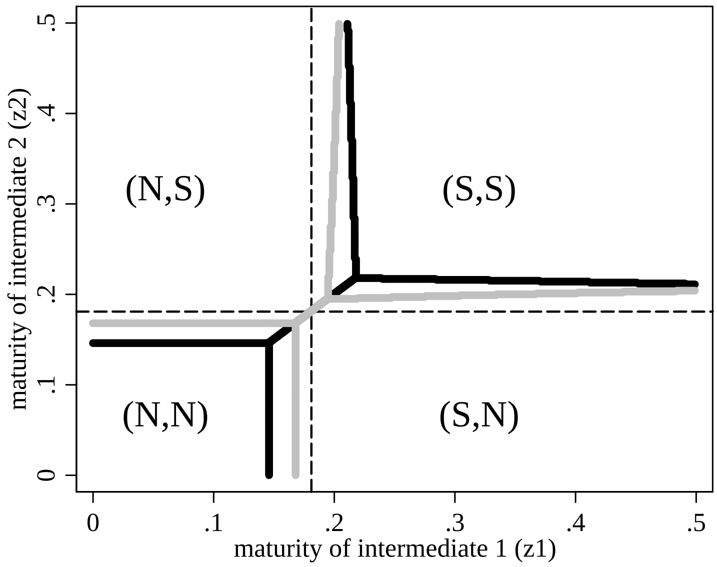
Appendix III Extension 3: complementary intermediates

A parameter α in the production function below zero implies complementary inputs. An extreme case is the Leontief production technology which is the limiting case for $\alpha \rightarrow -\infty$. It modifies the analysis and predictions only in a few places. In particular, Proposition 1 is unchanged and optimal sourcing of intermediates is still determined by maturity threshold functions.

A first difference is the second type of irregular product cycles is not possible anymore.[1] An increase in the maturity of a part that is sourced in South, say part 1, cannot change the optimal sourcing of another South-sourced part 2 back to North in this case. In contrast, it is possible now that a similar increase in z_1 brings about a usual product cycle transition for part 2 from North to South even when z_2 is constant.

This can be seen on Figure A.2 which displays all the possible equilibria in the two-intermediates case. Along a horizontal line that corresponds to a constant z_2 but rising z_1, optimal sourcing could move from the (S,S) to the (S,N) equilibrium as the grey boundary for $\alpha = 0.65$ was crossed. However, for the downward-sloping black boundary, corresponding to $\alpha = -8$, a similar increase in z_1 moves the firm from equilibrium (S,N) to (S,S), i.e. a regular product cycle.

Figure A.2 All sourcing equilibria in the two-intermediates case with complementary inputs



Note: The lines partition the (z_1, z_2) space into four areas with different optimal sourcing configurations for different values of α. They correspond to $\alpha = -8$ (black), $\alpha = 0.65$ (grey), and the dashed straight lines are for $\alpha = \beta = 0.8$.

The intuition is that when parts are complements substitution is reversed. When the maturity for a part that is produced in South increases, it lowers its marginal procurement cost and increases demand for the other intermediates. This diminishes their underinvestment problem and facilitates offshoring additional parts. Hence, the sign of the derivative of the threshold $\partial z_2^* / \partial z_1$ equals the sign of α. If the two parts are complements, corresponding to the black lines in Figure A.2, the thresholds bordering the (S,S) area slope downward.

[1] The first type, where two intermediates exchange their maturity orderings and their optimal sourcing locations, is still possible.

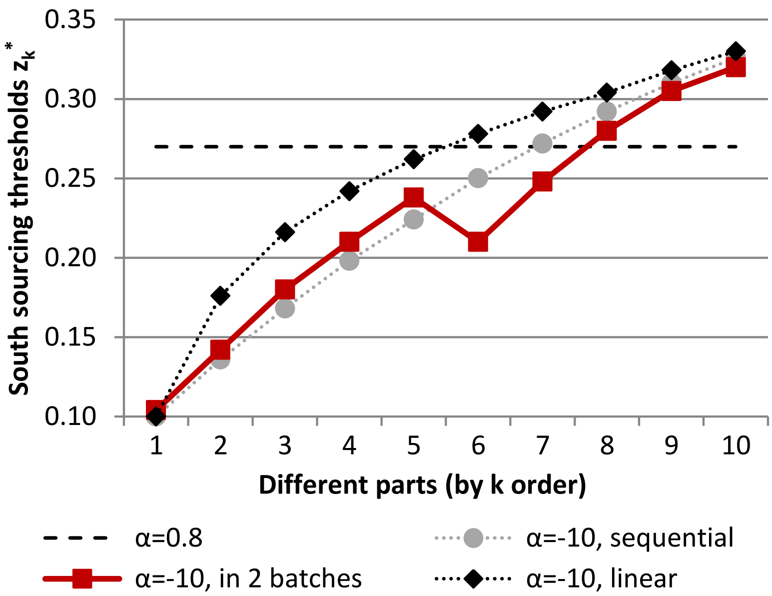
This reverse substitution also invalidates Proposition 3 for $\alpha < 0$ and it becomes impossible to order the successive maturity thresholds in general. The Proposition still holds for the first intermediate, $z_1^* < z_k^*$, but for higher order intermediates it is possible that $z_k^* > z_{k+1}^*$ if intermediates sourced in South mature a lot after z_k reaches z_k^* and before z_{k+1} reaches z_{k+1}^*. A sufficient increase in maturities z_1 to z_k might bring the firm to a part on the z_{k+1}^* threshold that is below the section of the z_k^* threshold that was relevant when part k was offshored. Hence it is possible that a later intermediate $k+1$ will be optimally offshored already at lower maturity level than was optimal for part k.[2]

Using specific assumptions on the evolution of the z-vector, we ran simulations as those reported in Figure 3 to investigate the effect of different maturing processes on successive sourcing thresholds. In Figure A.3, the dashed line again represents the $\alpha = \beta$ case, which leads to a constant threshold. The other three cases always assume $\beta = 0.8$ and $\alpha = -10$, i.e. strong complementarities between the intermediates.

In the case depicted by the grey circles, intermediates mature sequentially (as in Figure 3). Part 1 matures first all the way from 0 to 1 and only then the second part matures going from 0 to 1, etc. In the case depicted by the black diamonds, the first part gets a constant head start, but the second and later parts already start maturing before the previous parts reach $z = 1$. In both of these cases, the pattern is as before: sourcing thresholds become higher for successive intermediates. Offshoring is become gradually harder and requires higher maturity.

While extremely rare, we were able to construct an example with maturity thresholds that did not rise monotonically in the parts ordering by introducing bursts of maturing as follows. The first five parts mature together at the same pace all the way to unity before z_6 starts to increase. As a result, part 6 faces a much higher average maturity for parts already sourced in South than part 5 did when it made its sourcing switch: $z_1 = ... = z_5 = 1$ for part 6 while

Figure A.3 Sourcing thresholds with complementarities for alternative maturing processes



[2]In Appendix I of Van Biesebroeck and Zhang (2011) it is discussed why the proof of Proposition 3 breaks down for $\alpha < 0$.

$z_1 = ... = z_5 = z_5^*$ for part 5. Coupled with a strong complementarity in production ($\alpha = -10$) it leads to a higher derived demand for part 6 and as a result $z_6^* = 0.21$ is less than $z_5^* = 0.24$: part 6 is already offshoring at lower maturity. This example is indicated with the red squares in Figure A.3. Note that this maturing process does not satisfy the prediction of Proposition 3. It depends crucially on complementarities between intermediates and the downward sloping threshold between the (S,S) and (S,N) areas this generated in Figure A.2.

Appendix IV Model with complete contracts and fixed costs of producing in South

An alternative modeling approach to generate a product cycle in production is to replace the incomplete contracting friction for South production with a simple fixed cost. The firm will still delay offshoring a part to South until $z_k \geq z_k^*$ and the production advantage is sufficient to cover the fixed costs. The full model is described in Van Biesebroeck and Zhang (2011), here we illustrate a few highlights.

The set-up of the model is unchanged and as long as an intermediate is produced in North everything is identical. When the intermediate is produced in South, the level of x_l is now contractible and can be considered as chosen directly by the firm to maximize profits. The optimal input mix is still determined by equation (6) which reflects the benefit of producing low-skilled inputs in South. The absence of the contract friction now eliminates the factor 1/2 in equation (7) that determines optimal intermediate good quantity which now takes the same form when production is in North or South. For marginal decisions on intermediates produced in South (input-mix and y_k^*), the firm now considers the production cost c_s rather than the procurement cost MC_s.

The pricing rule for the final good is also unchanged and the profit equation simplifies to:

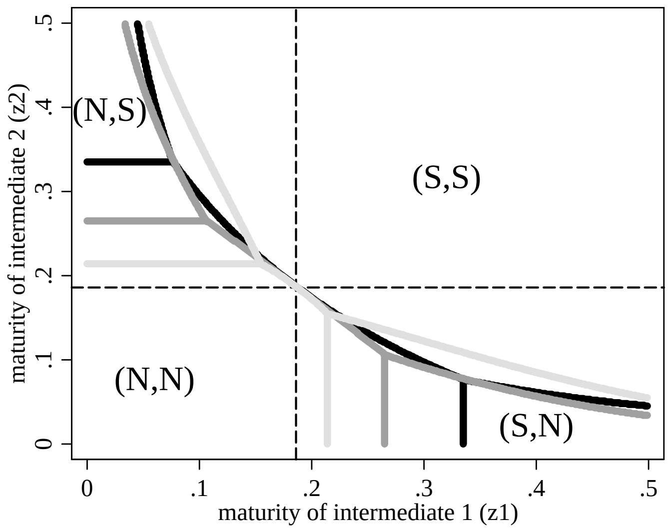
$$\pi(\tilde{c}, n_S) \quad = \quad (1-\beta)\,(K\tilde{c})^{-\frac{\beta}{1-\beta}} - f \cdot n_S. \tag{1}$$

It depends on n_S, the number of intermediates produced in South and on the average cost $\tilde{c}$ which is defined similarly as the $\widetilde{MC}$ aggregate before: $\tilde{c}^{-\frac{\alpha}{1-\alpha}} = \frac{1}{K}\sum_{l=1}^{K} c_l^{-\frac{\alpha}{1-\alpha}}$. The implicit markup on the cost of intermediates is now always $(1-\beta)$.

The profit equation nicely illustrates the different roles of the β and α parameters. If all intermediates are produced in North, $\tilde{c} = 1$ and the z parameters are irrelevant. Optimal quantities and price are determined solely by the number of intermediates and the substitutability of final products. This is because output in the CES production function rises with K and because the equilibrium price-cost ratio equals $1/\beta$. When at least one intermediate is sourced in South, the average marginal production cost declines ($\tilde{c} < 1$), equilibrium output is raised, and variable profits rise. The $\tilde{c}$ average is declining in the z index of a South-sourced intermediate, which now introduces a role for the α parameter.

For the case of $K = 2$, we illustrate graphically in Figure A.4 the sourcing equilibria for different values of α for all points in (z_1, z_2) space.

Figure A.4 All sourcing equilibria in the two-intermediates case with fixed costs



Note: The lines are the maturity thresholds that partition the (z_1, z_2) space into four optimal sourcing configurations for different values of α. They correspond to $\alpha = 0.65$ (light grey), $\alpha = 0.1$ (grey), $\alpha = -5$ (black), and $\alpha = \beta = 0.8$ (dashed straight lines).

If $\alpha < \beta$, the threshold $z_1^*(z_2)$ at which the firm is indifferent to source intermediate 1 in North or South is now a weakly decreasing function of the maturity level of intermediate 2. At the z_1^* threshold, the firm is indifferent between the two sourcing options for part 1. It has three segments, corresponding to three possible sourcing locations for part 2:

$$\begin{aligned} &\text{Intermediate 2 in North,} \quad \text{(S,N) versus (N,N):} && \pi(\tilde{c}, 1) - \pi(\tilde{c}, 0) = && f \\ &\text{Intermediate 2 in South,} \quad \text{(S,S) versus (N,S):} && \pi(\tilde{c}, 2) - \pi(\tilde{c}, 1) = && f \\ &\text{Simultaneous switch,} \quad \text{(S,S) versus (N,N):} && \pi(\tilde{c}, 2) - \pi(\tilde{c}, 0) = && 2f \end{aligned}$$

A fourth possibility, the indifference between (S,N) and (N,S), does not correspond to a segment of the threshold, because it can only lead to indifference if $z_1 = z_2$ and profits would be even higher if both parts are sourced in the same place. The three segments of the z_1^* threshold in Figure 2 in the incomplete contracting case were defined similarly. In that case, the fourth possibility lead to the segment of the threshold along the 45 degree line, while the simultaneous switch was never profit maximizing.

The possible implications for the product cycle in the case of the equilibrium represented by the light grey lines in Figure 7 now hold generally. First, if the maturities of several parts are sufficiently alike, they will switch sourcing simultaneously as they mature. Second, having one part already in South raises optimal output and makes offshoring other parts already profitable at lower maturity levels. Third, further maturing of a South sourced part might lead to a sourcing switch for another part, even if its own maturity does not change. Fourth, the first part is offshored at higher maturity than would be the case for sourcing over pure final goods.

All these predictions are more pronounced for a lower α parameter, i.e. for values further away from β which governs substitution by consumers. One can interpret the difficulty of substituting between intermediates (low α) as a complementarity. It increases the incentive to produce intermediates in the same place. It delay offshoring of the first intermediate, accelerates offshoring of part 2 when part 1 is already produced in South, and the segment separating the (N,N) and (S,S) areas is larger for lower α.

With fixed costs but without contract frictions, maturity thresholds for successive intermediates are unambiguously decreasing. When one intermediate is offshored, the marginal cost of the final product declines and its equilibrium output rises. Because $\alpha < \beta$ the derived demand for each intermediate is certain to increase, which makes it easier to recover the fixed costs of South production for any intermediates still produced in North. Simulation results in Van Biesebroeck and Zhang (2011) illustrate that this interdependency can be important quantitatively.

Several general results can be shown:

Proposition 1' *Given the skill intensity of all other parts, there exists a z_k^* threshold such that part k should be produced in North if $z_k < z_k^*$ and in South if $z_k \geq z_k^*$, with South production incurring a fixed cost.*

Corollary 2' *Once a part is sourced in South, no increase in the skill intensity of other parts will be able to switch optimal production of the part back to North.*

Proposition 3' *If $z_k \geq z_{k+1}$ for all k in $\{1, ..., K-1\}$, the sourcing thresholds that make the firm indifferent between North or South sourcing of intermediates k and $k+1$ satisfy $z_k^* \geq z_{k+1}^*$.*

Proposition 1' is the same as before, while the prediction in Proposition 3 reverses (and now even holds if $\alpha < 0$). Corollary 2 does not hold anymore, while the new Corollary 2' is not valid with incomplete contracting. Proofs are in Van Biesebroeck and Zhang (2011).