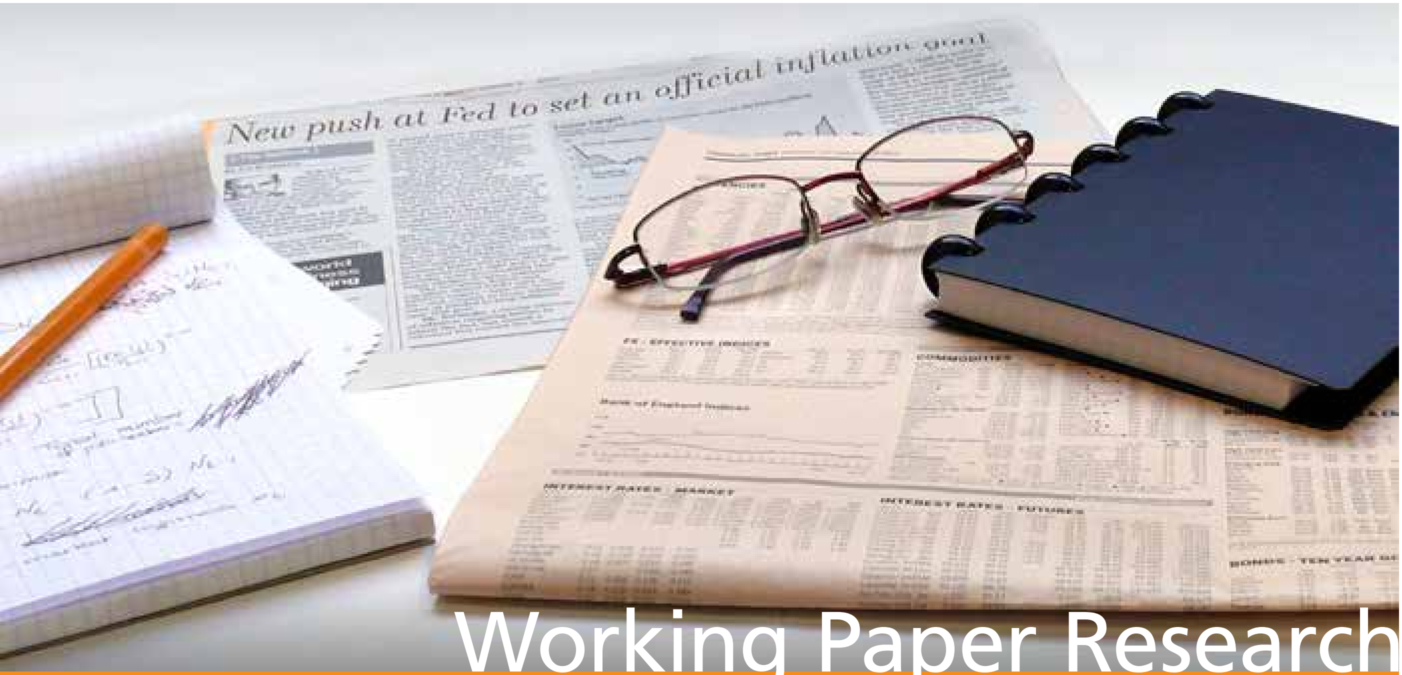
Why do manufacturing firms produce services ? Evidence for the servitization paradox in Belgium



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Abstract

The increasing role of services in GDP results from the growing share of service industries, but also from the fact that firms produce services along with goods. This paper investigates the determinants of service provision by manufacturing firms. First, it develops a model of differentiated products with, on the demand side, complementarities between the firm's goods and services, and, on the supply side, rivalry in the allocation of expertise between the production of goods and the provision of services. Second, it provides an econometric assessment of the determinants of servitization for manufacturing firms, using a fractional Probit model with heterogeneity, controlling for endogeneity with respect to unobserved firm characteristics. Both the theoretical model and empirical estimates point to a non-linear relationship between servitization and firm productivity. The relationship is further shaped by the sector environment as well as intrinsic characteristics of the goods and services supplied.

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Introduction

In recent decades, the provision of services has become increasingly important. In Belgium for example, the share of manufacturing industries in GDP declined from 0.21 in 1995-1999 to 0.16 in the recent 2010-2014 period, while the share of services went up from 0.63 to 0.68 over the same period. This is also apparent from the net job creation figures, with 161.8 thousand job losses in the manufacturing sector between 1995 and 2014 (one job in four), and 849.1 thousand jobs created in the service sector, an increase of 30%.

In developed countries, the growing share of the service sectors in aggregate GDP and employment- deindustrialisation - is now accompanied by a process of servitization. Servitization refers to the provision of services by a company whose main or initial activity is to produce and sell goods. For example, Rolls-Royce offers “power by the hour” contracts: packages of support services for aircraft engines. IBM, initially a hardware manufacturer, has shifted to service activities such as consulting, financing, training and so on, to offer a bundle of goods and services.

Servitization challenges the way we think about firms, production, consumption, and industry. For firms that engage in servitization, this represents a change in business, production and organisational models. It may affect the firm's performance in terms of profit, market power, survival, investment, employment, and so on. Engaging in servitization also represents a risky investment that does not always bring higher profits. Developing a new activity that differs from goods production involves costs, and organisational and managerial challenges. The risks of failure are significant, and profits associated with services may not compensate for those risks, or may be lower than the profits generated by producing goods alone. From the consumer’s point of view, when servitization amounts to providing packages of goods and services, it is also a way of increasing product differentiation. This broadens the range of product varieties and the value of the product for the consumer, who benefits from a goods-services package from a single supplier. Finally, servitization also modifies the extent and nature of competition both within the sector and between manufacturing and (some) service sectors.

Why do firms engage in servitization? That question has elicited many comments and studies in the business literature (Gebauer et al., 2005; Lee et al., 2016, among others). There are multiple reasons for developing service activities. Producing services may be motivated by diversification of activities and profit risks. Offering services along with goods may improve the attractiveness of the product or the brand, strengthening customer relationships, differentiating the product from that of competitors, and thereby securing a competitive advantage over competitors and creating barrier to entry. As such, the strategy may be adopted by large companies to protect or develop their market shares. But it may also be a way for small firms to penetrate a market with new and more tailored-made products. It may also be a necessary defensive strategy for firms faced with increasing competition from other firms that do provide the goods-services bundle. In sum, we face a servitization paradox where highly efficient manufacturing firms can afford the cost, financing and risks of developing a new service activity, but so can less efficient manufacturing firms that use a servitization strategy as a defensive strategy to remain active or grow.

The main objective of this paper is to provide some insights into this paradox. To do so, we propose a model of monopolistic competition with firm performance heterogeneity. This model allows us to conduct an econometric analysis of servitization from Belgian firm-level panel data over the period 1997-2013.

The issue of servitization has received substantial attention in the business literature, but theoretical and econometric evidence is scarce. Recent microeconomic papers that describe the servitization process are, for example, Bernard et al. (2016) and Crozet and Milet (2014). The former analyse the decline in manufacturing production in Denmark, focusing on firms that switch from manufacturing industries to service sectors. The latter describe the servitization process in France at the firm level, using available firm-level data on sales of goods and services. Their figures reveal substantial heterogeneity in the degree of servitization, even within industry; most firms sell few if any services, but some are heavily servitized. Finally, estimations by Dachs et al., (2014) for a set of firms across 10 European countries point to a non-linear relationship between firm size and servitization.

On the question of the relevant determinants of servitization, the theoretical literature is also limited. Lee et al. (2016) develop a duopoly model where the probability of manufacturers producing services depends, among other things, on the size of the market for the combined goods-services package, the complementarity between the use of goods and the consumption of services, and the firm's efficiency. Breinlich et al. (2014) analyse how changes in competition affect the relative production of goods as opposed to services. They develop a model where firms produce both goods and services and decide on the allocation of expertise to the production of goods and services. Following a decrease in the goods import tariff, the model predicts that firms reallocate expertise towards or away from the production of goods, depending on the elasticity of demand for goods relative to the elasticity of demand for services and the degree of expertise rivalry. Their empirical evaluation shows that reduced import tariffs on manufactured goods induced British firms to increase their provision of services.

Another strand of the literature on servitization has considered the effect of servitization on firms' performance. Crozet and Milet (2015) analyse the relationship between servitization and firms' characteristics such as size, employment or profitability. Ariu et al., (2016) investigate how exports of services affect exports of goods. In their model there is demand complementarity between services and goods. They show that the increase in goods exports that follows from the provision of services operates through a rise in quantities under monopolistic competition and through charging higher prices under oligopolistic competition. Applying their model to Belgian export data, they confirm that export sales increase when services are exported to the same destination as the goods, and that this result is driven by an increase in export prices and in the perceived quality of exported goods. Finally, a couple of papers examine whether the availability of services, for example through trade or FDI, helps (other) manufacturing firms to improve their performance (see, for example, Arnold et al., 2011; Fernandes and Paunov, 2012; Hijzen et al., 2011), their internationalisation through FDI (Gorg and Jabbour, 2016), or offshoring of intermediate inputs (Debaere et al., 2013).

This paper focus on the determinants of firm servitization. We first develop a theoretical model where there is complementarity in the demand for goods and services, and firms decide on the allocation of rivalrous expertise between the production of goods and the provision of services. As in the above-mentioned models, firms produce differentiated goods and services. On the demand side, as in Ariu et al. (2016), there is complementarity between goods and services. On the supply side, following Breinlich et al. (2014), when there is imperfect rivalry in expertise, firms may produce services along with goods without a major cost in terms of expertise resources. Our theoretical model suggests that the extent of servitization varies with firm characteristics, product characteristics and market conditions. First, servitization varies with firms' efficiency, but the relationship is likely to be non-linear. For different motives, both high-performance firms and low-performance firms may find it optimal to develop services provision. Second, the relationship between servitization and firms' efficiency depends on the degree of complementarity between goods and services, the degree of goods and services differentiation, and the degree of non rivalry in technology. Third, market conditions, in particular demand elasticities and the extent of competition, may shape this relationship. These factors imply that the relationship between servitization and firms' characteristics is likely to be nonlinear and may well differ from one sector to another.

We evaluate empirically the determinants of firm servitization. We rely on three firm-level datasets for Belgium over the period 1997-2013. Total firm sales are reported in VAT declarations. We match this information with firms' total sales of industrial goods from the Survey of Industrial Production. We then compute the servitization rate as the ratio of service sales, measured as the differences between total sales and goods sales, over total sales. We estimate a fractional Probit model controlling for endogeneity with respect to unobserved firm characteristics. Our specification allows for nonlinear effects of firm-level variables, e.g. TFP, age, size and average wage. We also include sector-level controls, i.e. the degree of competition, the mean and standard deviation of the servitization rate, as well as time and sector effects. For robustness we also consider a Tobit model. Consistent with our model and previous discussion, our results point to a non-linear relation between servitization and firm characteristics. This suggests that it is not only the most efficient firms that provide services, but that less efficient firms may also engage in servitization. Furthermore, estimation by broad sector of economic activity confirms that, as well as the intrinsic characteristics of the goods and services supplied by the sector, such as differentiation and complementarity, the sector environment may also shape the relationship between servitization and firms' performance.

The rest of the paper is organised as follows. Section I provides a survey of the relevant literature. Section II develops our theoretical model. Section III describes the data used in the empirical analysis in section IV. Section V concludes.

I – Survey of the literature

In this section, we first review relevant theoretical models before examining econometric analyses of servitization.

Breinlich et al. (2014) investigate how an increase in competition affects services provision using a model with monopolistic competition and differentiated products. Firms produce both goods and services and decide on the allocation of their exogenously given expertise to the production of goods and services according to relative market conditions, the firm's total expertise level, the demand elasticity for goods and for services and, importantly, the degree of rivalry in the use of expertise. At one extreme of full rivalry, any extra use of expertise in the production of goods implies a reduction of the same amount of expertise in the production of services; at the other extreme of non rivalry the full amount of expertise can be used for both the production of goods and the production of services. Their setup differs from our model in that demand for goods is completely separable from demand for services; in other words there is no complementarity between the use of goods and the use of services. They focus on how trade liberalisation affects the relative provision of services and production of goods. They show that a decrease in goods import tariffs affects market conditions leading to reallocation of expertise between services and goods production. Intuitively, firms reallocate expertise towards goods production the greater the demand elasticity for goods compared to the demand elasticity for services and when there is more rivalry in technology. Conversely, they reinforce services production the greater the demand elasticity for services relative to that for goods, and the less rivalry there is in expertise. These effects are greater the larger the firm's stock of expertise.

Ariu et al. (2016) develop a model with one-way complementarity of services to goods i.e. use of the goods is a prerequisite for use of the service. Complementarity is defined at the firm-product-market level. Exporting entails fixed costs, and exporting services implies an additional fixed cost. Providing services together with goods is a function of the extent of complementarity between goods and services, as well as market conditions. In addition, exporting services also depends on the firm's ability to pay the extra fixed cost entailed. The model predicts that offering services along with goods allows firms to increase their export performance. The authors show that the channel through which export performance increases depends on the type of competition. Under monopolistic competition, bi-exporters sell a larger volume of goods than standard exporters, while under oligopolistic competition, services provision allows bi-exporters to increase their market power and consequently to charge higher prices for their goods sold abroad.

Lee et al. (2016) consider two alternative market outcomes when there is complementarity between goods consumption and services consumption. They compare firms' profits where goods and services are produced by two different types of firms - manufacturers produce goods and service firms produce services – or by a single firm - a servitized manufacturer that sells both services and goods. Demand for the goods depends on the price and quality of the goods as well as on the price and quality of services (provided by the same firm or another firm). In this model, manufacturers have an incentive to provide services as well (i) when the market for the combined goods-services package increases, (ii) the greater the complementarity between the use of goods and the consumption of services, (iii) the more the two options (goods and services separately versus goods-services package) are substitutable, (iv) the higher the cost efficiency and improved quality of the servitized manufacturer.

Econometric evidence on the determinants of servitization is scarce. Dachs et al., (2014) investigate the determinants of servitization for a set of firms in 10 European countries. Their results highlight a U-shaped relationship between firm size and servitization. Servitization is also positively related to product complexity and firms' product innovation, and is more present in intensive innovation sectors.

Crozet and Millet (2014) use a large firm-level dataset that reports information on goods sales and service sales. From this, they measure the servitization rate as the share of service revenues in firms' total sales, excluding retail services. They highlight two types of firms: most firms sell few if any services, while some specialise in services provision. For example, one third of the firms obtain at least 80% of their sales from services. The authors also draw attention to a negative relationship between servitization and firm size, labour productivity, capital intensity and average firm wage. Finally, estimating the number of workers employed by manufacturing (services) firms involved in the production of services (goods) reveals that the servitization phenomenon is 8% larger than suggested by traditional measures based on sector classification alone.

Crozet and Millet (2015) analyse the relationship between servitization and firms' characteristics. More precisely, they investigate the impact of starting to provide services on firms' outcomes. Restricting their attention to firms that obtain less than half of their turnover from the provision of services, they find that servitized firms are larger (in terms of employment and turnover) and more profitable than non-servitized firms. Furthermore, firms that start selling services experience an increase in their profitability of between 3.7% and 5.3%, they increase their total sales by 3.7%, and increase their sales of goods by 3.6%. Their results also highlight that the benefits of starting to sell services are greater for micro and small firms than for larger ones, and vary across sectors. In particular, providing services boosts sales of goods in some sectors, but becomes a substitute for them in others.

Breinlich et al. (2014) consider firms' service revenues relative to goods revenues. They rely on a Poisson model to explain why most firms do not produce services and to account for the skewed distribution of revenues. The specification relates the goods/services revenue ratio to export and import trade tariffs for goods and services, controlling for firms' productivity and labour input prices as well as year effects, sector-level time trends, and firm effects. Estimating the model on firm-level data for the United Kingdom over 1997-2007, their results suggest that a reduction in goods import tariffs leads to an increase in service revenues, and that the effect is more pronounced for firms with a higher R&D stock, and smaller for capital-intensive firms.

Ariu et al. (2016) evaluate how exporting both goods and services (being bi-exporters) to a given destination impacts on goods export sales to that destination, using transaction export data by firm, destination and product for Belgium over 1997-2005. To control for the endogeneity of being a bi-exporter, they rely on a two-step IV estimation strategy. Their results show that export sales increase when services are exported to the same destination, controlling for the number of products exported to that destination, firms' export experience on that product market, and apparent labour productivity, multinational status and belonging to the service sector. Furthermore, this effect is mainly attributable to an increase in export prices, and shows up in an increase in the perceived quality of the goods exported, as measured by the Khandelwal et al. (2013) index.

II – An illustrative Model

To examine the servitization paradox, we assume an economy with two monopolistic competition sectors. In these manufacturing and service sectors there is a continuum of firms.

Each firm is multiproduct in the sense that it produces a differentiated good and a differentiated service simultaneously. There is a continuum of consumers of the same type with a utility function separable and linear in the numeraire good. Therefore, there are no income effects on the monopolistic competition sectors and we can perform a partial equilibrium analysis. Our model is similar to that of Breinlich et al. (2014). Firms are multiproduct and heterogeneous in their level of productivity. Furthermore, they can allocate some specific knowledge across goods and services production processes according to the degree of non- rivalry in respect of the specific knowledge. However, to deal explicitly with goods and services that are complementary for consumers, for example when we consider that services may adapt the goods' functionality (Cusumano et al., 2015), we use a different demand system based on a quadratic utility function as in Melitz and Ottaviano (2008).

Demand

Preferences are defined over a continuum of differentiated varieties of goods and services indexed by *i*. The utility of a representative consumer *c* of *L* consumers in the economy is given by

$$\begin{aligned} U = \alpha \int_0^N q_i^c di - \frac{1}{2}\gamma_g \int_0^N \left(q_i^c\right)^2 di - \frac{1}{2}\left(\int_0^N q_i^c di\right)^2 \\ + \alpha \int_0^N y_i^c di - \frac{1}{2}\gamma_s \int_0^N \left(y_i^c\right)^2 di - \frac{1}{2}\left(\int_0^N y_i^c di\right)^2 + \theta \int_0^N q_i^c y_i^c di \end{aligned} \tag{1}$$

where N is the mass of consumed varieties[1], $\alpha, \gamma_g, \gamma_s$ and θ are positive parameters, q_i^c and y_i^c represent for *c* his individual consumption levels of good variety *i* and of service variety *i* (produced by the same firm *i*), respectively. The parameters γ_g and γ_s express the specific consumer's preferences for goods and services. They also index the degree of product differentiation between the varieties. When $\gamma_g = 0$ ($\gamma_s = 0$), the varieties are perfect substitutes and both markets are homogeneous. Consequently, consumers only care about their consumption level over all varieties $Q^c = \int_0^N q_i^c di$ $\left(Y^c = \int_0^N y_i^c di\right)$. The degree of product differentiation increases with γ_g (or γ_s) as consumers give increasing weight to the distribution levels of consumption across varieties. In the same vein, the parameter θ expresses the degree of complementarity between variety *i* of good and variety *i* of service. This degree ranges from zero when the varieties of goods and services are independent for consumers to γ_g (γ_s) when the varieties are perfect complements for them (Vives, 1984).

The inverse demand by the representative consumer *c* for the variety of good and for the variety of service produced by firm *i* can be written as follows:

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1 To simplify the model, we assume an identical mass for good varieties and service varieties. We assume also that all varieties are consumed.

$$p_i^g = \alpha - \gamma_g q_i^c - Q^c + \theta y_i^c \tag{2}$$

$$p_i^s = \alpha - \gamma_s y_i^c - Y^c + \theta q_i^c \tag{3}$$

By assuming that consumers are uniformly distributed across the range of varieties, equation (2) and equation (3) can be inverted to yield the linear market demand for good and service varieties *i*,

$$q_i = L\left(a - bp_i^g - cp_i^s + d\bar{P}^g + e\bar{P}^s\right) \tag{4}$$

$$y_i = L\left(a' - cp_i^g - b' p_i^s + e\bar{P}^g + d'\bar{P}^s\right) \tag{5}$$

where

$$a \equiv \frac{\alpha}{(\gamma_g\gamma_s - \theta^2)}\left(\gamma_s + \theta - \frac{(\gamma_g+\theta)(\gamma_s+\theta)+\gamma_s^2+\theta\gamma_g}{(\gamma_g+N)((\gamma_s+N)-\theta^2}\right),$$

$$a' \equiv \frac{\alpha}{(\gamma_g\gamma_s - \theta^2)}\left(\gamma_g + \theta - \frac{(\gamma_g+\theta)(\gamma_s+\theta)+\gamma_g^2+\theta\gamma_s}{(\gamma_g+N)((\gamma_s+N)-\theta^2}\right) b \equiv \frac{\gamma_s}{(\gamma_g\gamma_s-\theta^2)}\ ,\ b' \equiv \frac{\gamma_g}{(\gamma_g\gamma_s-\theta^2)},\ c \equiv \frac{\theta}{(\gamma_g\gamma_s-\theta^2)},$$

$$d \equiv \frac{\gamma_s(\gamma_s+N)+\theta^2}{(\gamma_g\gamma_s-\theta^2)\left((\gamma_g+N)((\gamma_s+N)-\theta^2\right)}, d' \equiv \frac{\gamma_g(\gamma_g+N)+\theta^2}{(\gamma_g\gamma_s-\theta^2)\left((\gamma_g+N)((\gamma_s+N)-\theta^2\right)},$$

$$e \equiv \frac{\theta(\gamma_g+\gamma_s+N)}{(\gamma_g\gamma_s-\theta^2)\left((\gamma_g+N)((\gamma_s+N)-\theta^2\right)},$$

L represents a continuum of consumers, $\bar{P}^g = (1/N)\int_0^N p_i^g di$ and $\bar{P}^s = (1/N)\int_0^N p_i^s di$ are the average prices of goods and services, respectively that are taken as exogenous by firm *i*. The parameters *a* and *a'* are both positive if the mass of the consumed variety is sufficiently large ($N \geq 1$) and if the degree of differentiation exceeds the degree of complementarity ($\min(\gamma_g, \gamma_s) > \theta$) or in other word if goods and services cannot be perfect complements. Note that when these two conditions are fulfilled, the other parameters of the demand functions are positive.

Production

As in Breinlich et al. (2014), firm i's production functions for goods and services are assumed to take the following form:

$$q_i = T_{ig}L_{ig} \tag{6}$$

$$y_i = T_{is}L_{is} \tag{7}$$

where T_{ig} and T_{is} are firm-specific productivity terms and the firm's labour inputs used to produce goods and services are L_{ig} and L_{is}. The labour cost w is given and is the same across sectors.

The production processes of firms are increasingly based on assets such as the invention of new processes and/or products, and improvements in employee skills and brand image. These factors labelled as "intangible capital," represent a key component of firms' knowledge which is crucial to their productive performance (Marrocu et al., 2012; Bontempi and Mairesse, 2015). When firms produce goods and services simultaneously, it may not be possible to separate the knowledge embodied in the service from that embodied in the good, especially in the case of "adapting" services (Cusumano et al., 2015). This non-separability may result from the fact that knowledge has the characteristics of a public good. More precisely, knowledge can be considered as non-rivalrous in its use in the production of goods and services. Hence, increased use of knowledge to produce a good may not reduce the knowledge available to produce a service. Following Breinlich et al. (2014), the stock of knowledge is assumed fixed within the firm and a CES function is used to model the degree of non-rivalry in knowledge across the production of goods and services,

$$T_i = \left(T_{ig}^t + T_{is}^t\right)^{\frac{1}{t}} \tag{8}$$

where $t \in (0,\infty)$. For high values of t, knowledge can be considered as non-rivalrous. In other words, when $t \to \infty$, the firm can use the full amount of T_i simultaneously in both production processes.

Firm i maximises its profit by choosing the optimal prices (p_i^g, p_i^s), and the optimal amounts of knowledge to allocate to the production of goods and services (T_{ig}, T_{is}). The objective function can be expressed as follows:

$$\max_{p_i^g, p_i^s, T_{ig}, T_{is}} p_i^g L\left(a - bp_i^g - cp_i^s + d\bar{P}^g + e\bar{P}^s\right) + p_i^s L\left(a' - b' p_i^g - cp_i^s + e\bar{P}^g + d'\bar{P}^s\right) - w\left(L_{ig} + L_{is}\right)$$

$$s.t. \quad T_i = \left(T_{ig}^t + T_{is}^t\right)^{\frac{1}{t}} \quad q_i = T_{ig} L_{ig} \quad y_i = T_{is} L_{is} \tag{9}$$

From the first order conditions, we can get the optimal selling prices of goods and services given by,

$$p_{ig} = \frac{\left(\gamma_g \gamma_s - \theta^2\right)}{2}\left(\left(ab' - a'c\right) + \left(b'd - ce\right)\bar{P}^g + \left(b'e - cd'\right)\bar{P}^s + \frac{w}{\left(\gamma_g \gamma_s - \theta^2\right)T_{ig}}\right) \tag{10}$$

$$p_{is} = \frac{\left(\gamma_g \gamma_s - \theta^2\right)}{2}\left(\left(a'b - ac\right) + \left(be - cd\right)\bar{P}^g + \left(bd' - ce\right)\bar{P}^s + \frac{w}{\left(\gamma_g \gamma_s - \theta^2\right)T_{is}}\right) \tag{11}$$

It is easy to check that the "composite" parameters obtained in both expressions are all positive. Consequently, higher average selling prices on markets for the good and the service allow the firm to charge a higher optimal own-price. As the good and the service are complementary, each own price of the firm depends on both average prices even though the effect of $\overline{P}^s$ on p_{ig} is lower than the effect of $\overline{P}^g$ on p_{ig} $(b'd - ce > b'e - cd')$ since it is assumed that the good and the service are not perfect complements. The same reasoning is applied in the case of the service price. However, the effect of $\overline{P}^s$ on p_{is} is now greater than the effect of $\overline{P}^g$ $(bd' - ce > be - cd)$. Both optimal prices of firm *i* also depend negatively on T_{ig} and T_{is}. A larger amount of knowledge allocated to the production of one type of product improves the productivity of the more competitive firm, which can therefore reduce its optimal price. However, as the global amount of knowledge is given (T_i is fixed) and knowledge is partially a non-rival product $(T_{is} = \left(T_i^t - T_{ig}^t\right)^{\frac{1}{t}})$, the firm cannot improve its competitiveness simultaneously on both markets. From the first order conditions on T_{ig} and T_{is}, the rule for the optimal allocation of knowledge between goods production and services production is given by,

$$\frac{T_{is}}{T_{ig}} = \left(\frac{y_i}{q_i}\right)^{\frac{1}{1+t}} \tag{12}$$

where $q_i = \frac{L}{2}\left(a + d\overline{P}^g + e\overline{P}^s - \frac{bw}{T_{ig}} - \frac{cw}{T_{is}}\right)$ and $y_i = \frac{L}{2}\left(a' + e\overline{P}^g + d'\overline{P}^s - \frac{cw}{T_{ig}} - \frac{b'w}{T_{is}}\right)$ that represent the optimal quantities of goods and services sold by the firm. Note that the amount of knowledge in goods and the amount of knowledge in services both have a positive effect on the quantities of goods and services sold. But as the goods and services are not perfect complements ($\gamma_g > \theta$ and $\gamma_s > \theta$), the impact of T_{ig} on q_i is greater than the effect of T_{is}. The same result holds for y_i with T_{is} now having a larger impact. Expression (12) highlights that the optimal ratio between services and goods sold depends on the distribution of knowledge for the production of goods and the production of services. The larger the amount of knowledge allocated to the service sector, the higher the output ratio. However, the relationship in (12) is nonlinear and the knowledge ratio is exactly equal to the output ratio only if $t=0$. This corresponds to the case where knowledge is perfectly rivalrous in its use across output types: increased use of knowledge in producing one output type results in a corresponding reduction in the amount of knowledge available for producing the other output type. When *t* increases, the rivalry in use of knowledge decreases and the knowledge ratio increases by less than a proportional change in the output ratio. This first analysis is partial as it does not capture the fact that optimal quantities of goods and services also depend on the amount of knowledge T_{is} and T_{is}. Next, a comparative statics analysis must be carried out.

Comparative statics

Our analysis diverges from Breinlich et al. (2014) in two ways. First, we do not analyse the effects of fiercer (international) competition on servitization. Rather, we focus on how the firm allocates its knowledge to the production of services according to its total amount of knowledge, or similarly according to its global productive performance. The objective is to provide some insights into the "service paradox" in the sense that the most productive firms are not the only ones to engage in servitization; less productive firms may also do that (Gebauer et al., 2005; Crozet and Milet, 2015). Second, following Ariu et al. (2016), we consider that goods and services may be viewed by consumers as complements. As θ is defined over $\left]0, \min(\gamma_g, \gamma_s)\right[$, the model can take into account various degrees of complementarity. Using the typology proposed by Cusumano et al. (2015), we assume the degree of complementarity is lower for "smoothing" services - that just facilitate the purchases of goods by customers - than for "adapting" services that are able to expand the goods' functionality or help the customers to develop new uses for the goods.

The total differential of expression (12) with respect to T_{is} and T_i allows us to determine what happens to servitization at the equilibrium when the exogenous amount of knowledge in the firm changes. Hence, we have,

$$\frac{\mathrm{d}T_{is}}{\mathrm{d}T_i} = \left(\frac{T_{is}}{T_i}\right)^{1-t}\left(\frac{T_{ig}A}{T_{is}B + T_{ig}A}\right) \tag{13}$$

where

$$A = \left(\frac{cwL}{2T_{ig}}\left(\left(\frac{T_{is}}{T_{ig}}\right)^{1+t}\frac{b}{c} - 1\right) - (1+t)y_i\right) \quad \text{and} \quad B = \left(\frac{cwL}{2T_{is}}\left(\left(\frac{T_{ig}}{T_{is}}\right)^{1+t}\frac{b'}{c} - 1\right) - (1+t)q_i\right).$$

When $\frac{\mathrm{d}T_{is}}{\mathrm{d}T_i} > 0,$ an increase in the productive performance of the firm raises its servitization. However as indicated in Table 1, the effect of knowledge/performance on servitization is not so clear-cut and depends in the first instance on the signs of *A* and *B*. In most cases, an increase in service provision follows a positive productivity shock, but in two cases (Cases 3-a, 4-a), an increase in servitization follows a negative productivity shock.

Table 1: relationship between the total amount of knowledge and servitization

Case n°1 A>0 and B>0	$\frac{dT_{is}}{dT_i} > 0$
Case n°2 A<0 and B<0	$\frac{dT_{is}}{dT_i} > 0$
Case n°3-a A<0 and B>0	$\frac{dT_{is}}{dT_i} < 0$ if $T_{is}B + T_{ig}A > 0$
Case n°3-b A<0 and B>0	$\frac{dT_{is}}{dT_i} > 0$ if $T_{is}B + T_{ig}A < 0$
Case n°4-a A>0 and B<0	$\frac{dT_{is}}{dT_i} < 0$ if $T_{is}B + T_{ig}A < 0$
Case n°4-b A>0 and B<0	$\frac{dT_{is}}{dT_i} > 0$ if $T_{is}B + T_{ig}A > 0$

Expression A corresponds to the total differential of T_{ig} on both sides of (12). Rewriting A as $A = \frac{1}{(T_{ig})^{1+t}}\left(\frac{Lwb}{2T_{ig}}(T_{is})^{1+t} - \frac{Lwc}{2T_{ig}}(T_{ig})^{1+t}\right) - (1+t)y_i$, the left term in A is the difference between, first the direct effect of T_{ig} on the quantity of goods sold weighted by $\left(T_{is}\right)^{1+t}$, and, second, the indirect effect of T_{ig} on the quantity of services supplied weighted by $\left(T_{ig}\right)^{1+t}$. Note that the indirect effect exists because the goods and services are complementary, and that the indirect effect is lower than the direct effect. Therefore, one can have $A > 0$ so long as T_{ig} is not too large compared to T_{is}. By contrast, when T_{ig} is much larger than T_{is}, the weighted indirect effect can exceed the weighted direct effect and one can have $A < 0$. The same reasoning applies for B that corresponds to the total differential of expression (12) with respect to T_{is}. B is the difference between the direct effect of T_{is} on the quantity of service supplied multiplied by $\left(T_{ig}\right)^{1+t}$ and the indirect effect of T_{is} on the quantity of goods sold multiplied by $\left(T_{is}\right)^{1+t}$. However expressions A and B also depend on the quantities of goods and services sold and on the degree of non-rivalry (t), which renders the analysis technically challenging. Fortunately, it is easy to establish the forms of the implicit functions A=0 and B=0 with respect to T_{is} and T_{ig}. Furthermore, we have to consider the constraints that the quantities of goods and services must both be positive, or equivalently that $T_{ig} > bw/d\bar{P}^g$ and $T_{is} > b'w/d'\bar{P}^s$.

Figure 1 allows us to present more comprehensive findings drawn from our model. The lines $T_{ig} > bw/d\bar{P}^g$ and $T_{is} > b'w/d'\bar{P}^s$ delimit the area of values of T_{is} and T_{ig} such that both goods and services are produced. The curves *A=0* and *B=0* delimit the areas where both *A* and *B* are positive (green area, corresponding to Case 1), and *A<0* and *B>0* (Case 3-a and 3-b), *A>0* and *B<0* (Cases 4-a and 4-b), and both *A* and *B* are negative (corresponding to Case 2). Finally,, the condition $T_{is}B+T_{ig}A=0$ defines the limit between Case 3-a (yellow area) andCase 3-b (blue), and between Case 4-a (red area) and Case 4-b (blue). We distinguish between highly efficient firms - those with a high *Ti* - and less efficient firms. The former are in the North-East area of Figure 1, where both T_{is} and T_{is} are themselves high. The less efficient firms are represented in the coloured areas.

> *Proposition 1*: A negative productivity shock (a decrease in T_i) leads the less efficient firms to increase their servitization (an increase in T_{is}) in two mutually exclusive situations:
>
> 1) Knowledge is allocated more to goods provision ($T_{ig} > T_{is}$) and knowledge is not too rivalrous (*t*>1);
> 2) Knowledge is allocated more to service provision ($T_{is} > T_{ig}$) even if knowledge is rivalrous.

The first case of Proposition 1 corresponds to case 3-a. In this case, less efficient firms find it optimal to reinforce their presence in the service sector (yellow area) because a large part of their knowledge (T_i) is allocated more to goods provision than to service provision. Firstly, in *B*, the direct positive effect of T_{is} on y_i is amplified by $\left(T_{ig}\right)^{1+t}$ while the indirect effect of T_{is} on q_i is limited by $\left(T_{is}\right)^{1+t}$ because of the relatively small value of T_{is}. The difference between these two effects is positive and that favours the realisation of $B > 0$. For *B>0* when $\left(T_{ig}/T_{is}\right)^{1+t} b'/c > 1$ or equivalently $\left(T_{ig}/T_{is}\right)^{1+t} \gamma_g/\theta > 1$, it should also be verified that the right-hand term of *B* ($(1+t)q_i$) is small. That is very likely in this case since the firm's performance is weak, so q_i is low.[2] Secondly, *A* must be negative. This arises when the indirect effect of T_{is} on q_i is amplified by $(T_{ig})^{1+t}$. The left-hand term of *A* is negative when $\left(T_{is}/T_{ig}\right)^{1+t} b/c > 1$ or equivalently $\left(T_{is}/T_{ig}\right)^{1+t} \gamma_s/\theta > 1$. Since firms produce a limited quantity of services, the right-hand term of *A* $(-(1+t)y_i)$ is more negative when there is less rivalry in technology (*t* is large). Thirdly, to verify $\mathrm{d}T_{is}/\mathrm{d}T_i < 0$, the additional condition that $T_{is}B + T_{ig}A > 0$ must also hold. Taken together, these conditions indicate that allocating a large

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2 Here we do not have to discuss the degree of non-rivalry since *t* is introduced as factor of q_i in the right-hand term of *B* while it appears as exponent in the left-hand term.

part of knowledge to goods provision is not enough to allow the firm to intensify its servitization. It is also necessary that knowledge is non-rivalrous or equivalently that *t* is large enough so that the firm is not discouraged from intensifying its servitization.

The second case of proposition 1 corresponds to case 4-a in Table 1, where $\mathrm{d}T_{is}/\mathrm{d}T_i < 0$, and to the red area in Figure 1. Here, T_{is} is sufficiently large compared to T_{ig} to amplify the direct effect of T_{ig} on q_i (*A*>0) and the indirect effect of T_{ig} on y_i (*B*<0). The additional condition that $T_{is}B + T_{ig}A < 0$ is likely to be verified, since the firm has already allocated a large part of its knowledge to service provision and *B<0*, even for some weak degrees of non-rivalry in knowledge. In this case, where the allocation of knowledge to service provision exceeds the allocation of knowledge to goods provision, it is optimal for the firm to increase its servitization, as knowledge becomes scarcer. As *A* and *B* correspond to the total differential of both sides of (12) with respect to T_{ig} and T_{is}, respectively, we have $dT_{ig}/dT_{is} = B/A$. In case 3-a and case 4-a, we can then conclude that a decrease in knowledge leads to a decline in goods provision.

Having examined the cases where $\mathrm{d}T_{is}/\mathrm{d}T_i < 0$, we now turn to the cases where it is not systematically verified for less efficient firms. A positive productivity shock may increase the servitization of this type of firms even if the allocation of knowledge is unbalanced between service provision and goods provision. This corresponds to case 3-b and 4-b, the blue area in Figure 1. As previously mentioned, case 3-b arises because there is too much rivalry in knowledge allocation. When *t* is low, it is more likely that we have $T_{is}B + T_{ig}A < 0$, leading the firm to intensify its presence in the production of goods. Furthermore, case 4-b may challenge case 4-a only when knowledge is not sufficiently unbalanced in favour of service provision. Then we can have $T_{is}B + T_{ig}A > 0$ and consequently $\mathrm{d}T_{is}/\mathrm{d}T_i > 0$. Note that from $dT_{ig}/dT_{is} = B/A$ in case 3-b and case 4-a, we can conclude that a decrease in knowledge now implies an increase in goods provision.

If the allocation of knowledge is more balanced between both production activities, a positive (negative) productivity shock induces an increase (decrease) in the amount of knowledge transferred to the production of services (green area, case 1, *A*>0 and *B*>0). This condition is fulfilled if (i) the first terms of A and B are both positive. This happens if the weighted direct effect of T_{ig} on q_i exceeds the weighted indirect effect of T_{ig} on y_i in *A* and the weighted direct effect of T_{is} on y_i exceeds the weighted indirect effect of T_{is} on q_i in *B*. This is immediate in the case of a perfectly balanced allocation of knowledge ($T_{is}=T_{ig}$), because by assumption, the complementarity between goods and services (θ) is relatively low compared to the degree of product differentiation on both markets (γ_g and γ_s). In the more general case, the condition is verified if we have simultaneously $\left(T_{ig}/T_{is}\right)^{1+t} b'/c > 1$ (or equivalently $\left(T_{ig}/T_{is}\right)^{1+t} \gamma_g/\theta > 1$) and $\left(T_{is}/T_{ig}\right)^{1+t} b/c > 1$ (or equivalently $\left(T_{is}/T_{ig}\right)^{1+t} \gamma_s/\theta > 1$) ; (ii) the last terms of *A* and *B* are not too negative. This is the case the greater the rivalry concerning knowledge, or equivalently the lower the value of *t*, and when the firm's performance is weak, i.e. when q_i, y_i are small.

> *Proposition 2:* A positive productivity shock always leads more efficient firms to intensify their servitization.

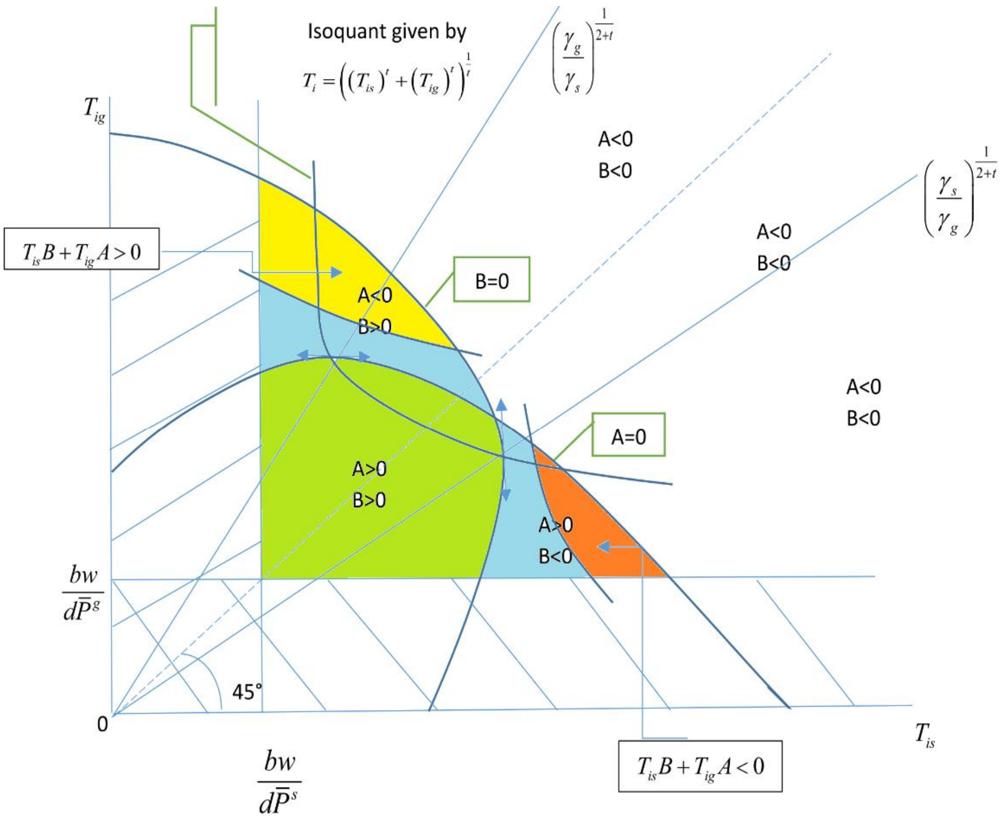
The more efficient firms are in the North-East area of Figure 1. In this area, T_i is high, then T_{is} and T_{ig} are themselves high. As expected, the more efficient firms react to a productivity shock in allocating more knowledge to both service provision and goods provision, as *A* and *B* have the same sign. Note that in this area, *A* and *B* are simultaneously negative. This means that the right-hand terms of both expressions, i.e. the quantities of goods and services sold, are dominant over the left-hand terms, i.e. whatever the sign of the difference between direct effect and indirect effect in *A* and *B*.

> *Proposition 3:* when competition is weak and the degree of complementarity between goods and services is high, the less efficient firms are present on the markets and are engaged in servitization like the efficient firms.

From conditions $T_{ig} > bw/d\bar{P}^g$ and $T_{is} > b'w/d'\bar{P}^s$, it appears immediately that for low market prices, $\bar{P}^g$ and $\bar{P}^s$, the less efficient firms are on the fringe, outside both markets. In that case, on very competitive markets, servitization is not a strategy that these firms can use to stay in the market. More interestingly, a high degree of complementarity allows the less productive firms to be present in both markets and to benefit from servitization ($\partial bw/d\bar{P}^g / \partial\theta < 0$). In fact, through θ, there is a "bonus" for consumers if they buy goods and services from the same firm, and the higher θ, the larger this bonus.

To sum up, our model indicates that the inverted U-shaped relationship between servitization and firms' performance may exist but is not systematic. Less efficient firms can increase their service provision when hit by a negative productivity shock in some cases. But in other cases, firms may find it optimal to decrease their service provision, especially when knowledge is rivalrous. Furthermore, as shown in Figure 1, the more efficient firms may find it optimal to use a servitization strategy. In this case, the relationship between servitization and performance is always positive. Note that when goods and services cannot be easily bundled or when competition on the service market is fierce, the efficient firms (like the less efficient firms) prefer not to engage in service provision. Ultimately, empirical analysis must be used to determine whether the U-shaped relationship between servitization and firms' performance is verified.

Figure 1: Degree of servitization and firms' performance



III – Data description

The analysis relies on firm-level data for Belgium over 1997-2013. It combines three data sources: the Survey of Industrial Production, VAT returns, and the Central Balance Sheet Register. This section describes the construction of our variables.

To construct a measure of servitization we use data from the Survey of Industrial Production and VAT returns. The first reports the amount of industrial goods sold by 8-digit product for each firm in the survey. It covers just over 4000 firms per year, mostly in the manufacturing sector. We aggregate data at the firm level to obtain firms' sales of goods. We complement this information with data on total sales as reported by firms in VAT returns. These report firms' turnover and consumption of intermediate inputs on a monthly or quarterly basis, depending on the firm's size, and the information is aggregated at the firm-year level. We control for the amount due to "processing on commission", also available in the Survey of Industrial Production dataset. We measure services as the difference between total sales and goods sales including processing on commission. To adjust for reporting errors, we exclude servitization rates below -0.05 or above 1.05; and winsorize the remaining observations at the [0, 1] range. Contrary to Crozet and Millet (2014, 2015) we do not exclude retail activities from the firms' services.

Additional firm-level variables are based on VAT declarations and balance sheet data. Firms' sales and intermediate input consumption are taken from the former. Balance sheet data are used for the remaining variables: value added, employment, average wage and labour cost, investment and capital. For balance sheet data, we perform a small set of corrections concerning dates and years or an apparently erroneous number of months in the annual accounts.[3] After that, the annual account information was annualised[4] and extrapolated. The sector of activity is determined according to the most commonly reported NACE codes available for each firm over the period, converted to the NACE-Rev2 classification where necessary. We use the 2-digit NACE-Rev2 deflators published in the National Accounts to obtain the real values of the nominal variables. We rely on value added, investment and intermediate consumption deflators.

We construct a set of firm-level characteristics. Employment is defined as the average number of employees in Full-Time Equivalents over the year. Size is the log of employment. The firm's average wage is given by the firm's wage bill over the average number of employees in Full-Time Equivalents over the year. The firm's age is based on the official starting date of the company.

To construct a measure of Total Factor Productivity, production function coefficients are estimated according to the methodology of Ackerberg et al., (2015). We rely on data on firms' value added, capital stock at the beginning of the year, average number of employees in Full-Time Equivalents over the year, and intermediate inputs consumption. Investment in physical capital is used as the proxy variable. Production function coefficients are estimated at the level of broad macroeconomic sectors, to ensure a sufficiently large sample size for each sector. Table A1 in Appendix A reports the estimated production function together with t-stat and number of observations by broad economic sector. Table A.2 in the Appendix reports descriptive statistics of the firm-level variables used to explain servitization, namely TFP, age, employment, and wage. Table A.3 reports moments of the distribution of TFP across sectors.

We also construct a set of sector-level variables at the 2-digit NACE Rev2 level. The yearly Herfindahl index is constructed on the basis of firms' sales as reported in the exhaustive sample of VAT returns. We also consider two measures of the extent of servitization within the sector. We compute the mean and standard deviation of the servitization rate at the sector and year level. The mean servitization rate aims to capture imitation effects, whereby firms may follow their competitors' strategy in terms of servitization. Furthermore, a low dispersion across servitization rates may, for instance, reflect the fact that goods and services in the sector can be readily bundled, so that all firms have to provide goods along with services.

In the analysis below, we focus on firms with at least 20 employees, active in the manufacturing sector over the period 1997-2013. More precisely, we consider firms classified as belonging to NACE Rev2 classification between 10 and 33. A firm is considered as active if it reports positive employment, total assets and nominal fixed tangible assets above 100 euro. We exclude coke and refined petroleum products sector because the number of

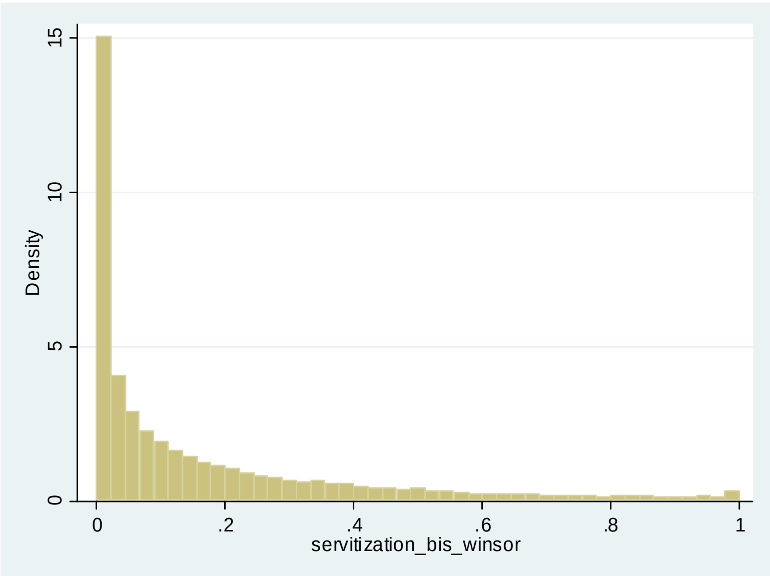
[3] For example, when the year-end date was 2 January 2005, we changed the date to 31 December 2004. By doing this we attributed the values reported in the annual accounts to the year 2004 instead of 2005.

[4] Flows are adjusted by taking a weighted average of t and t+1 flows. Stocks are adjusted by adding to the current year stock the weighted change in stocks between the current and next year. The procedure attributes a missing value when there is not enough information to reconstruct the entire year, for example when information about the first months or the last months of a given year is missing. This does not apply to the last year in which the firm is observed, or to flows in the first year that the firm is covered.

observations in the sector is far too small. Our final sample includes 37,228 observations, covering 3,538 firms over the period 1997-2013.

Servitization of the manufacturing sector is not a minor phenomenon. In our sample, one quarter of aggregate sales of manufacturing firms are related to services, on average, over 1997-2013. As shown in Figure 2, the distribution of servitization is very unequal with most firms selling few services, or none at all. In this sample, servitization reaches at least 5% in 56% percent of the cases. Consistent with Crozet and Millet (2014), we find that 87% of firms sell some services.[5] However, the number of firms providing services decreases rapidly with the degree of servitization. The degree of servitization is close to zero in a very large fraction of the cases; in the first quartile, the figure is around 0.25, and the in last decile it is around 0.50, i.e. servitization is above 50% in only 10% of the cases.

Figure 2 – Histogram of the servitization ratio for Belgian manufacturing firms, 1997-2013



Sources: Survey on Industrial Production and VAT declarations, and Central Balance Sheet Office
Sample of firms with 20 employees or more

We then examine differences across broad sectors of economic activity, defined as groups of NACE-Rev2.0 sectors. As shown in Table 2, the servitization rate varies across sectors. Chemical and pharmaceutical industries have median servitization rates around 20%. At the other extreme, wood and metal have median servitization rates at around 3 percent. Furthermore, there is substantial heterogeneity within sectors as evidenced by the interquartile range, or the gap between the 5th and the 95th percentiles.

5 They find that, in 2007, 83% of French manufacturing firms sold services.

Table 2 – Servitization rate by broad sector of economic activity

	# obs	mean	sd	p5	p25	p50	p75	p95
Food, beverages and tobacco	5803	0.17	0.22	0.000	0.013	0.077	0.246	0.657
Textiles, wearing apparel and leather	3304	0.18	0.26	0.000	0.008	0.063	0.244	0.839
Wood, paper and printing	4044	0.11	0.18	0.000	0.002	0.030	0.117	0.540
Chemicals	2800	0.28	0.26	0.000	0.068	0.204	0.418	0.815
Pharmaceutical products	584	0.25	0.22	0.006	0.075	0.193	0.374	0.685
Rubber and plastics, and other non-metallic mineral products	5199	0.17	0.20	0.000	0.020	0.104	0.262	0.587
Metal	6466	0.14	0.23	0.000	0.000	0.031	0.151	0.701
Computer, electronic and optical products, electrical equipment	2285	0.21	0.26	0	0.007	0.091	0.323	0.814
Machinery and equipment	3258	0.19	0.25	0.000	0.008	0.091	0.287	0.794
Transport equipment	1348	0.17	0.21	0.000	0.022	0.101	0.244	0.652
Furniture; other manufacturing	1974	0.14	0.20	0	0.002	0.045	0.216	0.565
Repair and installation of machinery and equipment	163	0.21	0.28	0	0.000	0.084	0.295	0.794
Total	37228	0.17	0.23	0.000	0.008	0.071	0.247	0.707

To illustrate whether servitization is associated with higher output sales or is a substitute for the firm's production of goods, we run two types of analysis. The first relates the log of goods sales on an indicator dummy for services provision, sector and year effects. The second focuses on firms that do provide services and regresses the log of goods sales on the log of service sales, year and firm effects. Results by broad sector of economic activity are reported in Table 3 below. The first set of results suggests that in most of the cases, except textiles, leather and wearing apparel, within a sector, firms that provide services have higher sales of goods, though that may just reflect firm size. In the second type of analysis, we include firm and year effects and focus on firms that sell some services. The results indicate different patterns across sectors. In some sectors, goods sales have increased with the increase in services provision, while in others, selling services has been accompanied by a reduction in goods sales. Note, however, that this statistical evidence reflects whether service provision allows firms to increase their goods sales or to sell services instead. What our theoretical model highlights and explains is complementarity in the *demand* for goods and services.

Table 3 – Goods sales and servitization

	Dserv>0	(std)	R^2	services	(std)	R^2
Food, beverages and tobacco	0.329***	(0.055)	*0.04*	0.022***	(0.004)	*0.92*
Textiles, wearing apparel and leather	-0.368***	(0.065)	*0.17*	-0.040***	(0.007)	*0.88*
Wood, paper and printing	-0.05	(0.046)	*0.11*	-0.008***	(0.003)	*0.93*
Chemicals	0.057	(0.131)	*0.01*	0.042***	(0.011)	*0.88*
Pharmaceutical products	0.495	(0.500)	*0.02*	-0.051**	(0.021)	*0.93*
Rubber and plastics, and other non-metallic mineral products	0.180***	(0.052)	*0.03*	-0.006*	(0.003)	*0.92*
Metal	0.039	(0.039)	*0.15*	-0.020***	(0.003)	*0.89*
Computer, electronic and optical products, electrical equipment	0.273***	(0.090)	*0.01*	-0.027***	(0.007)	*0.89*
Machinery and equipment	0.056	(0.067)	*0.03*	-0.008*	(0.005)	*0.90*
Transport equipment	0.079	(0.159)	*0.08*	0.028***	(0.008)	*0.93*
Furniture; other manufacturing	-0.049	(0.056)	*0.01*	-0.021***	(0.004)	*0.91*
Repair and installation of machinery and equipment	-0.470	(0.303)	*0.05*	-0.030	(0.029)	*0.73*
Year effects	Yes			Yes		
Sector effects	Yes			No		
Firm effects	No			Yes		

Notes: Dserv = 1 for firm that sell services: services is the log of service sales
Standard errors in brackets; *** p<0.01, ** p<0.05, * p<0.1

The next section examines whether servitization is associated with other firm characteristics, productive efficiency, labour cost and sector characteristics.

IV – Empirical investigation

In this section, we evaluate the theoretical predictions of the model and provide an econometric assessment of the determinants of servitization, based on the data described in the previous section. We first discuss the appropriate econometric estimation procedure, then present and discuss the empirical estimates.

The variable explained in our model is the rate of servitization of firms, which is a continuous variable defined between 0 and 1, inclusive. As a result, it is not possible to use the ordinary least squares method that suffers from the same defects as when it is applied to dichotomous variables. There are several convergent estimation methods for models[6] in which the explained variable is a fractional variable defined on the interval [0,1].

[6] The fixed effects two-limit Tobit Type I suffers from the incidental parameters problem and its estimation may be biased and inconsistent. See for more details, Honoré (1992). Nevertheless, a correlated random effects Tobit Model may be estimated in a convergent way, see appendix B. Ramalho et al. (2016, 2017) discuss some alternative estimators for factional response models with panel data. Nevertheless, the suggested estimators can be applied only when y is defined on the interval]0,1] or [0,1[but not on [0,1]. Using a Poisson model is not a solution either because it models y >=0 and not 0<= y <=1.

We follow the method proposed by Papke and Wooldridge (1996) and generalized to panel data by Papke and Wooldridge (2008). This method makes it possible to relax the strong hypothesis on the density function of the perturbations posed by the two-limit Tobit Type I model, namely $u|x \sim N(0, \sigma^2)$. This method is based on the idea that we can specify a model for $E(y|\mathbf{x})$ in a way that ensures predicted values of y are in (0,1). Papke and Wooldridge (1996) following Gouriéroux et al. (1984), propose to estimate this model by a Quasi Maximum Likelihood Estimator (QMLE). This estimator is called QMLE fractional logit or probit regression regression, depending upon the law (the link function) used. It makes it possible to question the hypothesis of strict exogeneity of *x* by using the Chamberlain-Mundlak device (see Papke and Wooldridge, 2008). Nevertheless, it is well known (see Greene, 2011, and Wooldridge, 2010) that, contrary to the linear model, ignoring the heteroscedasticity in a logit-Probit model may lead to seriously biased and non-convergent estimations. So, in order to estimate a fractional response model with an unbalanced panel framework, the conditional variance should be allowed to vary with the nature of the unbalanced character of the sample. Consequently, we estimate a fractional probit/logit model with multiplicative heteroscedasticity.

We present the estimation results of the fractional Probit model with multiplicative heteroscedasticity below.[7] An alternative estimation strategy could rely on the two-limit Tobit Type I correlated random effects model. A discussion of this model and robustness results are given in Appendix B.

Our specification allows for nonlinear effects of firm-level variables and controls for time-varying sector characteristics, sector dummies and year effects. The model also includes the Chamberlain-Mundlak correction to control for endogeneity of regressors with respect to unobserved firm-specific effects. Standard errors are clustered at the firm level. Firm-level variables include TFP, age, size and average wage. Sector controls include the Herfindahl index, the industry average servitization rate and the standard deviation of the servitization rate within the sector. We include square terms of TFP to capture and test for the servitization paradox whereby both less efficient firms and more efficient firms may provide services as well as goods. Since TFP is a generated regressor, we report bootstrapped estimates in Appendix C.

[7] Although it is more common to report the marginal effects, we decided to report the coefficient estimates of TFP and its squared term to better highlight the U-shape relationship between servitization and TFP.

Table 4 - Fractional Probit model with heterogeneity

	(1)	(2)	(3)	(4)	(5)
tfp_{it}	-0.291***	-0.248***	-0.230**	-0.233***	-0.222***
	(0.102)	(0.093)	(0.091)	(0.087)	(0.085)
tfp_{it}^2	0.015***	0.013**	0.012**	0.011**	0.011**
	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)
age_{it}		-0.039*	-0.035	-0.025	-0.021
		(0.022)	(0.022)	(0.020)	(0.020)
$size_{it}$			-0.043***		-0.036**
			(0.015)		(0.014)
$wage_{it}$				0.136***	0.128***
				(0.031)	(0.031)
$\overline{servitization_{st}}$	1.424***	1.316***	1.297***	1.249***	1.229***
	(0.353)	(0.332)	(0.327)	(0.312)	(0.309)
$\sigma(\text{servitization})_{st}$	0.235	0.195	0.205	0.131	0.144
	(0.263)	(0.245)	(0.242)	(0.227)	(0.226)
$Herfindahl_{st}$	-0.131	-0.153	-0.142	-0.148	-0.140
	(0.159)	(0.151)	(0.149)	(0.140)	(0.140)
constant	0.067	-0.126	-0.265	-3.865***	-3.762***
	(0.840)	(0.782)	(0.791)	(1.043)	(1.037)
Observations	36850	36850	36850	36846	36846
Log likelihood	-16344	-16314	-16289	-16182	-16178

Notes: Robust (clustered by vat) standard errors in parentheses. All regressions include sector and year effects and the Chamberlain-Mundlak correction. *** p<0.01, ** p<0.05, * p<0.1

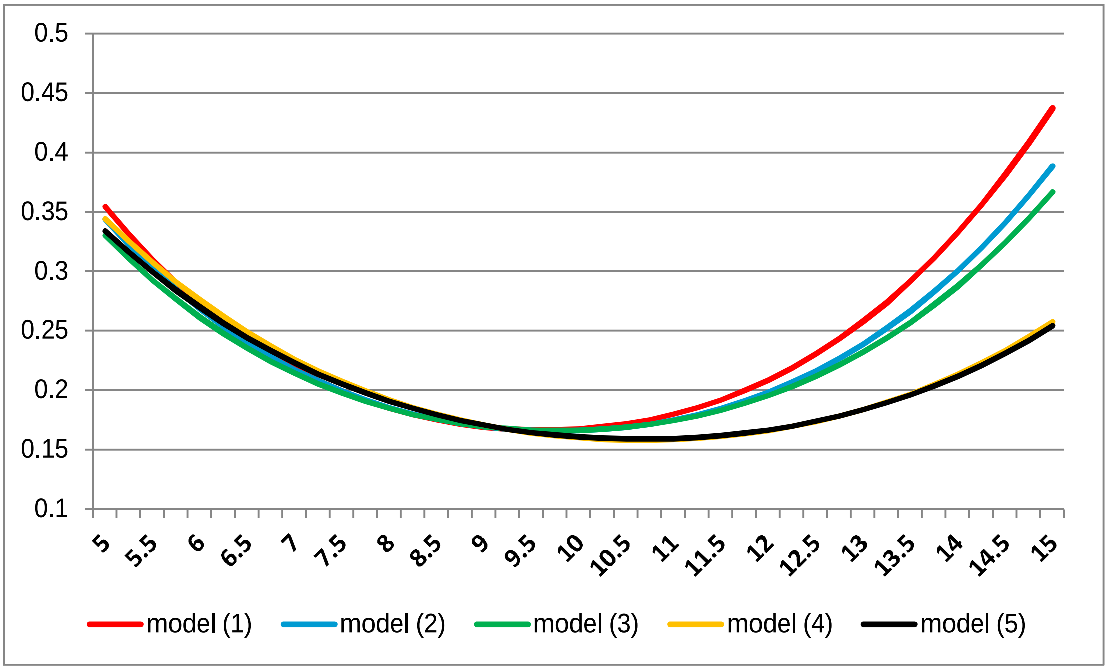
Estimates confirm the existence of a non-linear relationship between servitization and firms' productivity. As shown in column (1), both the level of TFP and its square are significant at conventional significance level. The signs of the coefficients point to a U-shaped relationship between firms' productivity and servitization, with a turning point at 9.70. It is not only low-productivity firms that develop services provision; high-productivity firms also do so. Concerning sector-level control variables, neither the Herfindahl index nor the standard deviation of the servitization rate by sector is significant (probably because of the small time-variation of these indicators). However, as expected, firm servitization rises in sectors where servitization increases. This may reflect an imitation process or greater potential for bundling services and goods on account of the specificities or technical characteristics of the sector's products.

Columns (2) to (4) include other firm-level variables as determinants of servitization. Servitization appears to be greater for younger and smaller firms. Firms' wages have a significant relationship with servitization. The last column of the Table brings all variables together in the model.

Although it is standard practice to report marginal effects, we illustrate the relationship between servitization and TFP by the predicted values of the dependant variable. Figure 3 plots average predicted values of servitization for alternative values of TFP. Servitization is high for low productivity firms, then decreases as TFP rises, then finally increases again for very high levels of productivity. For robustness tests, we also estimate a two-limit Tobit type I model. Appendix C compares the two types of estimates.

The Figure also illustrates the role of additional firm-level determinants for the relationship between TFP and servitization. Introducing firm age, size or wage does not substantially alter the relationship between servitization and TFP, although it slightly lowers the curvature of the servitisation-TFP relationship.

Figure 3 – Average predicted servitization rate for alternative values of TFP



Our empirical results of a non-linear relationship between firms' performance and servitization confirm the theoretical prediction of a servitization paradox whereby both low-performing and high-performing firms engage in service provision. Another prediction of the model is that this relationship is shaped by a set of factors related to the economic environment (e.g. the degree of competition), or product characteristics (the degree of product and service differentiation and the degree of demand complementarity between services and goods), or production factors (the degree of non-rivalry efficiency allocation between goods and services). All these factors suggest that the relationship between firms' performance and servitization is likely to vary across sectors.

We therefore estimate the above model by broad sector of economic activity, using the same classification as for the estimation of TFP. We retain only TFP as a firm-level determinant. However, due to the small size of the sample, most of the estimated parameters are insignificant. We exclude broad sectors for which there are less than 1500 observations, and the sector composed of sectors 19, 20, 21 which is too heterogeneous to be considered as a single sector in regard to servitization.[8] Table 5 below reports estimates for model (1) where the only firm-level variable is TFP. The point estimates show that there are differences in the relationship between servitization and TFP across sectors.

[8] It includes sectors as heterogeneous as coke and refined petroleum products, chemicals and pharmaceutical products.

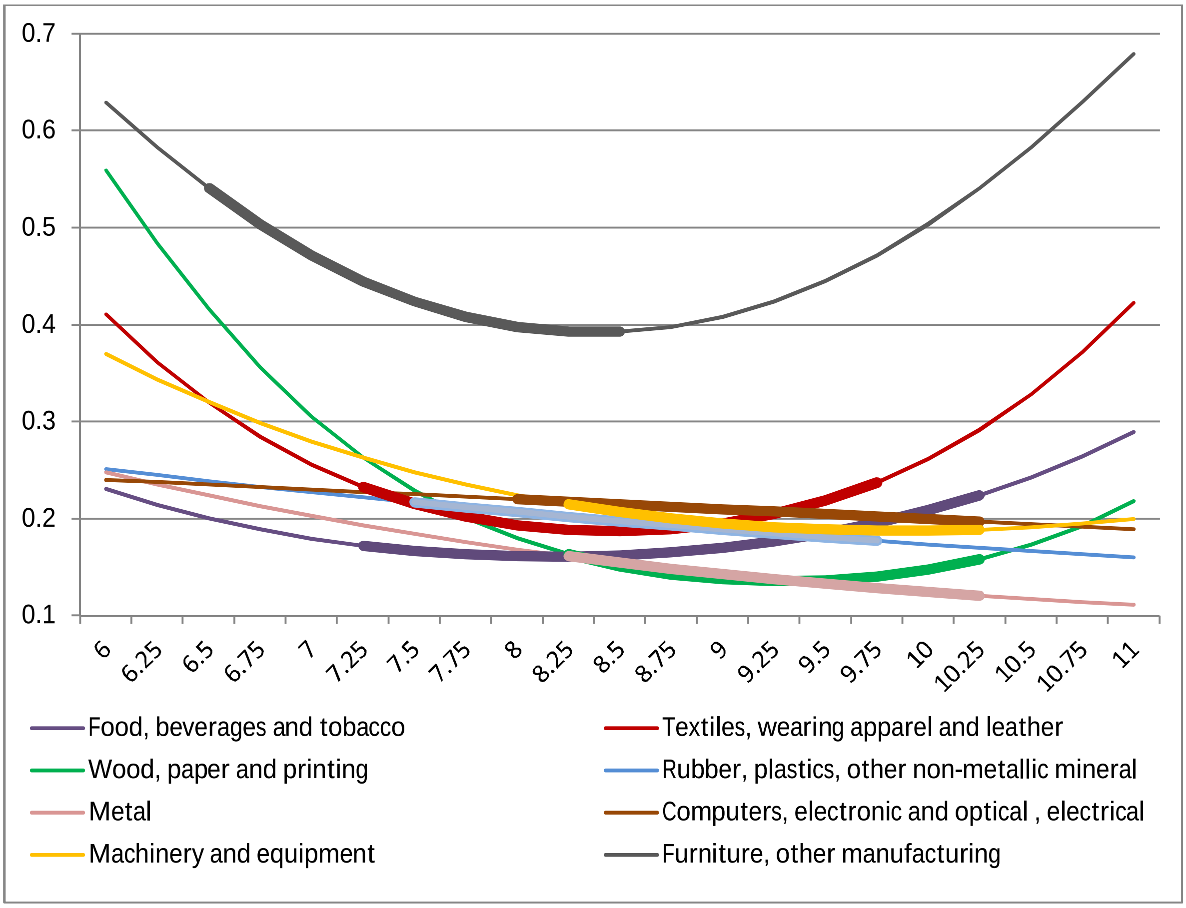
Table 5 - Fractional Probit model with heterogeneity by broad sector

	tfp_{it}		tfp_{it}^2		# obs.	log Likelihood
Food, beverages and tobacco	-0.414*	(0.215)	0.025*	(0.013)	5747	-2574
Textiles, wearing apparel and leather	-0.976	(0.655)	0.058	(0.039)	3272	-1529
Wood, paper and printing	-1.639**	(0.743)	0.088**	(0.039)	4012	-1330
Rubber and plastics, and other non-metallic mineral products	-0.091	(0.251)	0.002	(0.015)	5139	-2325
Metal	-0.125	(0.205)	0.004	(0.011)	6402	-2453
Computers, electronic and optical products, electrical equipment	-0.018	(0.447)	-0.001	(0.024)	2261	-1108
Machinery and equipment	-0.568	(0.611)	0.029	(0.033)	3239	-1564
Furniture, other manufacturing	-0.978	(0.788)	0.058	(0.049)	1962	-766.6

[1] **Standard-errors in parentheses**

Figure 4 illustrates the results by reporting the estimated servitization rate for a range of values of TFP. The bold line represents values that lie within the [P1-P99] range of the TFP distribution of the corresponding broad sector of economic activity. The Figure shows that, the relationship is essentially monotonically decreasing in rubber and plastic, in metal, and in computer, electronic and optical products. It is clearly U-shaped in the other manufacturing sectors, as in the textile and wood and paper sectors, for example.

Figure 4 – Average predicted servitization rate by sector for alternative values of TFP



V – Conclusion

Over the recent decades, manufacturing firms have increasingly offered services to customers along with goods. In some cases, firms that traditionally sold almost nothing but goods now obtain most of their turnover from services.

There are several possible reasons why firms provide the customer services themselves rather than outsourcing them or letting other firms provide them. Since developing a new activity - the provision of services - involves both costs and risks, one may argue that only the more efficient firms can afford it. However, less efficient firms may also use it as a defensive strategy, to differentiate their product and sustain market shares, or new firms may use it as an offensive strategy to capture a new market.

To gain a deeper understanding of these mechanisms, this paper develops a theoretical model that contains the following ingredients: the demand for differentiated goods and services is complementary, firms decide on the allocation of (rivalrous) expertise between goods production and services provision. Furthermore, expertise is unevenly distributed across firms; they operate under monopolistic competition. The model predicts that the extent of servitization depends on firm characteristics, product characteristics and market conditions. In particular, the relationship between firm efficiency and servitization is probably non-linear. Furthermore, the relationship varies across products and sectors.

These predictions are supported by our empirical evaluation. Estimating a fractional Probit model of servitization for Belgian manufacturing firms, we find a U-shaped relationship between servitization and firms' Total Factor Productivity, the curvature of which varies by sector.

Previous evidence (Ariu et al. 2016), Crozet and Millet, 2015) suggests that servitization increases a firm's performance in terms of profitability, sales and employment. What our paper shows is that evidence that a firm undertakes servitization gives no information on the current state of its performance. For example, it may be a strategy followed by a low performance firm to survive and gain market shares, or a way for a high performance firm to create a barrier to entry.

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Appendix A: Production function coefficients estimation

Table A1 : Estimates of production function per sector by the Ackerberg-Caves-Frazer method (1997-2013 period)

Sectorial Classification (Nace rev 2)	lnk	lnl	# observations
Food, Beverages and Tobacco (10, 11, 12)	0.203 (22.53)	0.752 (84.46)	44138
Textiles, Wearing Apparel and Leather (13, 14, 15)	0.225 (38.73)	0.686 (94.60)	18737
Wood, Paper and Printing (16, 17, 18)	0.173 (39.27)	0.736 (162.93)	36125
Coke, Chemicals and Pharmaceutics (19, 20, 21)	0.242 (28.83)	0.813 (84.20)	8613
Rubber, Plastic and Other Non-Metallic Mineral Products (22, 23)	0.215 (21.24)	0.740 (70.13)	23591
Basics Metals and Fabricated Metal Products (24, 25)	0.170 (59.58)	0.740 (237.80)	48114
Computers, Electronic, Optical products and Electrical Equipment (26, 27)	0.167 (16.49)	0.825 (59.69)	11643
Manufacture of machinery and equipment n.e.c. (28)	0.212 (0.79)	0.740 (2.69)	15193
Transport equipment (29, 30)	0.185 (21.92)	0.830 (81.96)	5022
Manufacture of furniture and other manufacturing (31, 32)	0.356 (1.06)	0.608 (1.97)	12520
Repair and installation of machinery and equipment (33)	0.182 (36.64)	0.787 (117.50)	8014

t student statistics in parentheses. Physical investment is used as a proxy and the capital stock is measured at the beginning of year.

Table A.2 – Descriptive statistics on firm-level determinants of servitization

	N	mean	std	p1	p25	p50	p75	p99
TFP	36857	9.10	0.65	7.23	8.75	9.16	9.52	10.43
age	37228	28	18	2	15	24	37	88
employment	37203	166	422	22	38	62	135	1987
average wage	37200	29821	10573	12358	22958	27892	34361	66335

Table A.3 - TFP distribution by broad sector of economic activity

	mean	std	p1	p25	p50	p75	p99
Food, beverages and tobacco	9.03	0.53	7.56	8.74	9.01	9.33	10.31
Textiles, wearing apparel and leather	8.84	0.48	7.42	8.58	8.85	9.13	9.98
Wood, paper and printing	9.50	0.42	8.45	9.26	9.49	9.73	10.57
Chemicals	8.70	0.43	7.47	8.45	8.71	8.96	9.75
Pharmaceutical products	8.38	0.52	7.15	8.06	8.31	8.57	9.95
Rubber and plastics, and other non-metallic mineral products	8.90	0.48	7.70	8.67	8.90	9.14	9.97
Metal	9.53	0.40	8.47	9.31	9.51	9.74	10.55
Computer, electronic and optical products and electrical equipment	9.57	0.48	8.34	9.29	9.59	9.88	10.61
Machinery and equipment	9.41	0.42	8.52	9.13	9.37	9.67	10.54
Transport equipment	9.13	0.43	7.91	8.92	9.16	9.39	10.14
Furniture; other manufacturing; repair and installation of machinery and equipment	7.64	0.41	6.72	7.39	7.63	7.87	8.72

Appendix B : robustness analysis. Alternative estimation.

For robustness we also estimate a two-limit Tobit type I model. This can be used in the context of corner solution models in which we observe a rate of servitization between 0 and 1. However in this case, a rate of 0 or 1 is an economic decision, i.e. the result of a firm's profit maximisation and not the result of a truncation process due to failure to observe the latent variable (see Wooldridge, 2010). By setting, $\alpha_1 = 0$ $a_1 = 0$ and $a_2 = 1$, we can model the latent variable $y^* = X\beta + u$ with $u|x \sim N(0,\sigma^2)$. y^* is the latent variable and so we define the observed rate of servitization as:

$y = 0$ if $y^* <= 0$

$y = y^*$ if $0 < y^* < 1$

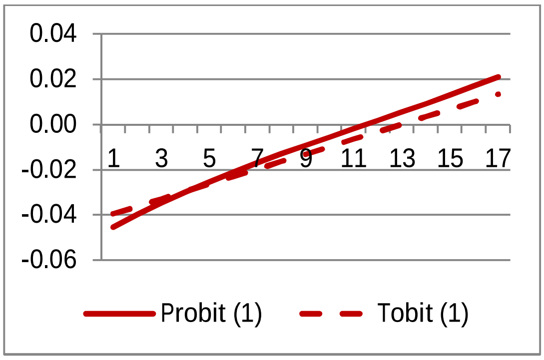
$y = 1$ if $y^* >= 1$

In fact, y^* has no real economic interpretation. The servitization rate cannot be lower than 0% or greater than 100% (even in a latent interpretation). It only restricts y, the variable of interest, to between 0 and 1. The model can be estimated in a convergent and asymptotically efficient way by the maximum likelihood method. This specification, besides being well adapted to the case of a variable fractional response, offers several other advantages. First, it adapts quite easily to the case of panel data (and hence to the unobserved heterogeneity of firms) in the context of the random effects two-limit Tobit Type I model. Second, it allows us to question the hypothesis of strict exogeneity of the covariates by using the framework of the correlated random effects Tobit model which is an adaptation of the Chamberlain-Mundlak method used for Probit models with random effects on panel data (see Wooldridge, 2010). However, this method may be non-convergent in the case of heteroscedasticity of disturbances (see Wooldridge, 2010).

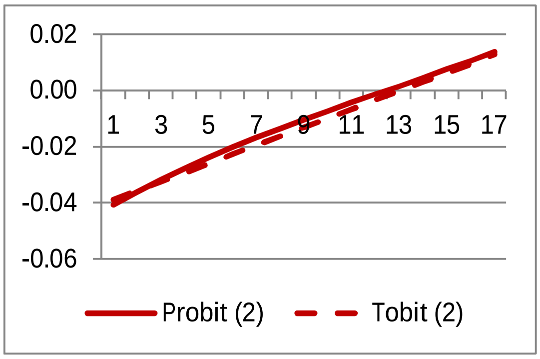
As in the fractional Probit model with heterogeneity, we include level and squared terms of firm-level determinants of servitization, and the same set of sector-level variables and other controls. The two models deliver essentially similar results, as illustrated by marginal effects for alternative values of TFP, reported in Figure B1 below.

Figure B - Average marginal effects of TFP for the fractional Probit model with heterogeneity (Probit) and a two-limit Tobit type I model (Tobit), for alternative sets of firm-level determinants.

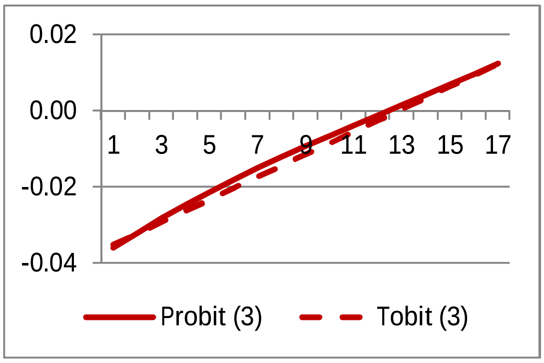
B.1 Model (1) with TFP



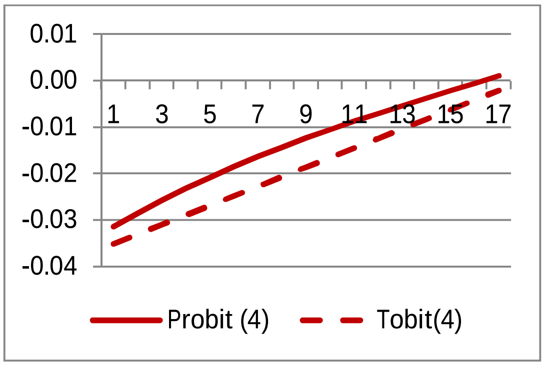
B.2. Model (2) with TFP and age



B.3. Model (3) with TFP, age and size



B.4. Model (3) with TFP, age, size and wage



Notes: Sector-level variables are set at their mean value, the reference sector is “food, beverages and tobacco” and the reference year is 2013

Appendix C : Bootstrap estimates of the fractional Probit model

Table C.1 - Fractional Probit model with heterogeneity

	(1)	(2)	(3)	(4)	(5)
tfp_{it}	-0.307*	-0.256*	-0.242	-0.196	-0.180
	(0.167)	(0.152)	(0.149)	(0.151)	(0.147)
tfp_{it}^2	0.015*	0.013	0.012	0.009	0.008
	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)
age_{it}		-0.025	-0.019	-0.015	-0.007
		(0.032)	(0.032)	(0.031)	(0.031)
$size_{it}$			-0.058**		-0.054**
			(0.025)		(0.025)
$wage_{it}$				-1.652**	-1.645***
				(0.643)	(0.638)
$wage_{it}^2$				0.086***	0.085***
				(0.032)	(0.032)
$\overline{servitization_{st}}$	1.816***	1.638***	1.611***	1.773***	1.724***
	(0.554)	(0.514)	(0.503)	(0.526)	(0.514)
$\sigma(\text{servitization})_{st}$	0.028	0.032	0.048	-0.129	-0.110
	(0.427)	(0.392)	(0.382)	(0.395)	(0.385)
$Herfindahl_{st}$	-0.195	-0.221	-0.206	-0.219	-0.208
	(0.254)	(0.238)	(0.231)	(0.239)	(0.232)

Bootstrap estimates using 500 replications. Bootstrap by firm.
Robust clustered) standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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