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# The Effect of Productivity on French Manufacturing Firms' Export-Initiation Timing: Evidence from Duration Models

by

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**Abstract** This paper investigates empirically the extent to which the time-horizon between firms' formation and initial export activity is determined by their productivity. To this end, discrete-time duration models with time-varying covariates are employed on a sample of French fabricated metal manufacturing firms: The Cox Proportional Hazards, Weibull, and Exponential model. Controlling for industry-effects, productivity is found to significantly shorten the formation-to-export time-span, as are firms' resources in terms of labour and investment into physical capital. Further, findings indicate that firms which enter markets later tend to initiate exports faster. Conversely, more capital-intensive firms appear to initiate exports more slowly. Various methodological concerns are raised, which have thus far not yet received attention. Specifically, the treatment of market-exit as a competing event, and the treatment of export-initiation as an event subject to a cure proportion are yet to be implemented in duration analyses of firms' pre-export time-span.

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# 1. Introduction

Economic theory almost universally treats time-horizons arbitrarily. Indeed, a lack of emphasis on, or improper incorporation of time is a frequently invoked criticism of the field (Turk, 2010; George & Jones, 2000; Melvin, 1990; Robinson, 1980; Rosenstein-Rodan, 1934). This is not to say time is not treated per se. Much of modern economics incorporates time-dependent elements via multiple periods, introduces preference-relations on or dis-/economies to time, and offers distinct equilibria over the short, medium, and long run (Boland, 1978). However, besides the frequently invoked argument that these treatments fail to properly account for the directionality of time, and thus path dependence of economic processes (Rosenstein-Rodan, 1934), they additionally are problematically arbitrary in one important regard: They generally do not offer sufficiently precise, if any predictions on the time-horizon over which economic processes occur, nor do they inherently offer fertile theoretical ground for empirical analyses of such time-horizons (one may or may not agree that *in the long run* is not sufficiently precise). This seems particularly problematic within trade theory.

As a discipline, trade theory is primarily concerned with the causes, dynamics, and (welfare) gains from trade. As such, these models are historically rooted in comparative-statics autarky-to-trade settings, which frequently compress a set of processes into four point-observations: (1) Firms enter markets in autarky, (2) autarky-equilibria realize, (3) autarky terminates, and (4) trade equilibria realize. This comparative-statics perspective is however not what makes the treatment of time 'particularly' problematic in trade theory. Indeed, much of economic theory is built on the progression between point-observations, and it should be acknowledged that transitions between them are generally understood as occurring through time, at least implicitly. Specific to trade theory is however, that the dominant sequence of states does not consider one crucial process at all: The process in which firms, from formation or termination of autarky, develop capacities required to enter foreign markets (Oesterle, 1997).

Indeed, although trade theory has increasingly departed from the easily aggregated 'representative firm', emphasising instead markets defined in large part by heterogeneity with respect to firms' productivity and domestic market-entry timing, this process is yet be be integrated theoretically (Melitz, 2003; Melitz & Redding, 2014). Perhaps due to this lack of theoretical basis, the rather small set of empirical analyses which considers time-horizons in trade-contexts explicitly, primarily examines the duration of trade spells (see e.g. Fugazza & Molina, 2011; Hess & Persson, 2011; Berthou & Vicard, 2015; Lawless & Studnicka, 2019; Nicita, Shirotori & Klok, 2013; Besedeš and Prusa, 2006a & 2006b; Brenton, Saborowski & Uexküll, 2010). Limited theoretical basis notwithstanding, if initially heterogeneous firms continuously develop productive capacities through time, then it seems probable that they enter foreign markets over heterogeneous time-horizons. It is precisely this proposition which this paper intends to investigate, and which informs its research question:

> *To what extent is the time-horizon between firms' formation and initial export activity determined by their productivity?*

To answer this question, this paper adopts a quantitative approach. Specifically, a set of discrete-time duration models is employed on a dynamic sample of French manufacturing firms in the fabricated metal manufacturing industry, controlling for both firm- and industry-characteristics. The utility of duration models, in brief, is twofold. Firstly, duration models (also *survival* and *event history models*) explicitly treat time elapsed until the occurrence of an event such as initial export activity as the 'dependent' variable, and thus allow for inferences on the effect that covariates have on the length of that time-span (Bürgel, Fier, Licht & Murray, 2004, p. 142). Secondly, duration analysis permits sampling in which the units of observation enter and exit observation at different points in time, such that analyses are not restricted to specific firm-cohorts (Clark, Bradburn, Love & Altman, 2003a).

Through this approach, this paper hopes to make contributions in two ways. In empirically testing the proposition that heterogeneous (i.e. differently productive) firms initiate exports over similarly heterogeneous time-horizons, this paper highlights the need for trade models in which such heterogeneity is accommodated. This certainly appears crucial for inquiries into the utility of different trade policies, where timing is a key concern, and where under heterogeneous formation-to-export time-spans we may expect that gains to trade realize in varying magnitudes depending on time elapsed. This paper's findings thus serve to inform theoretical research which aims to introduce such time-paths between firm-formation and export-initiation, i.e. via a productivity-conditioned time-path.

More immediately however, this paper adds to the very limited literature that treats firms' pre-export period empirically, and in particular the even smaller subset of that literature which employs quantitative, longitudinal models in which time is not treated as independent. Such approaches have thus far been sparse, but frequently pointed towards as an important area of research (Coviello & Jones, 2004; Acedo & Jones, 2007; Coeurderoy & Murray, 2008; Rialp, Rialp & Knight, 2004). Further, although this paper empirically follows pioneering works by Bürgel et al. (2004, pp. 147-51), Powell (2014), and Ilmakunnas & Nurmi (2010), it additionally addresses methodological issues that warrant careful consideration when duration models are deployed to analyze firms' pre-export time-horizon, but which thus far are yet to receive attention.

To this end, this paper proceeds as follows. Section 2 examines previous research. A theoretical framework is synthesized, and hypotheses are developed. Given the absence of well-established theory in this regard, firm-characteristics which empirically serve (purely) as control variables require careful consideration. Consequently, and for the reader's convenience, hypotheses on these firm-characteristics are formulated in Section 2 as well. The choice of sample, and operationalization of variables is discussed in Section 3. In turn, Section 4 introduces and motivates the choice of duration models, the additional sampling procedures that follow from it, and the limitations that must be borne in mind. Finally, results are presented and discussed in section 5.

# 2. Literature Review

## 2.1 Previous Research

Thus far, empirical research has focused primarily on the differences between firms which do export and those which do not, what we might call the 'exporter characteristics' literature. Only recently, and to a lesser extent, has attention been devoted to how those differences affect firms' formation-to-export time-horizon. However, like much of the sparse time-horizon literature, this paper to some extent relies on the assumption that if certain characteristics lead firms to engage in international activity, then differences in those characteristics should induce differences in the formation-to-export time-horizon between firms (Bürgel et al., 2004, p. 147). Thus, although only briefly, the empirical exporter-characteristics literature is considered here first.

In that empirical research, exporting firms are generally found to be older, larger in terms of physical resources, more productive, profitable, capital-intensive, and R&D-intensive than their non-exporting counterparts (see e.g. Bürgel et al, 2004, pp. 118-9; Aw & Hwang, 1995; Baldwin & Gu, 2003; Bernard & Jensen, 2004; Haidar, 2012; Roberts & Tybout, 1997; Hallward-Driemeier, Iarossi & Sokoloff, 2002). They further tend to have management with previous international experience or are foreign-owned (Bürgel et al., 2004, p. 119; Ilmakunnas & Nurmi, 2010; Hallward-Driemeier, Iarossi & Sokoloff, 2002), produce goods with low adjustment-costs of base products for end-users, or (relatedly) low sunk costs to foreign market entry (Bürgel et al., 2004, p. 119; Roberts & Tybout, 1997). There is however an emerging literature which specifically treats the time-span preceding firms' export-initiation – or internationalization more broadly – empirically.

Quantitative research in this literature frequently relies on duration models due to the advantages it offers (as briefly discussed in the introduction). For example, Bürgel et al. (2004, pp. 148-51) employ such a model on a sample of British and German SMEs. They find that large resource stocks, R&D investment and management with prior international experience significantly shorten firms' time to foreign entry, while high product adjustment-costs and/or entry entry costs lengthen the foreign-entry time-horizon. Ilmakunnas & Nurmi (2010) obtain similar results vis-à-vis resource stocks (number of employees) on a sample of Finnish manufacturing plants. They additionally find that high labour productivity, foreign ownership, positive spillovers (share of other exporters in domestic industry), and high human capital shorten the formation-to-export time-span. Finally, they find that capital-intensity shortens the time-span, although those findings are only (or more) significant when not controlling for employees' human capital characteristics (Ilmakunnas & Nurmi, 2010). Coeurderoy & Murray (2008) corroborate these findings on a sample of German and British firms. Again, firms with more (initial) resources, R&D investment, and management previously employed in multinationals tend to enter foreign markets faster.

Powell (2014) similarly employs a duration-model on U.S. law firms entering the Chinese market. Consistent with previously discussed findings, high (relative) size of resource-stocks (employees), and previous international experience are associated with faster entry. Additionally, organizational age and resources committed to the home-market are found to lengthen the formation-to-export time-span. Interestingly, their findings further indicate that the relationship between (relative) profitability and foreign-entry speed follows an inverted U-shape, with the least and most profitable firms entering more slowly than firms at the center of the profitability distribution. Further, in contrast to Ilmakunnas & Nurmi (2010), Powell's results indicate that large numbers of exporting competitors reduce the speed with which other firms initiate exports, i.e. instead of positive spillover effects, this indicates constraints to foreign entry.

There are however also approaches which do not rely on duration models. McNaughton (2001) for example employs an Analysis of Tables (ANOTA) model on Canadian manufacturing (micro-) firms. Results indicate that firms' supplying knowledge-intensive goods, operating in a market with few domestic, and/or many international competitors enter more rapidly[1]. Similar to Powell (2014), organizational age is found to negatively affect the formation-to-export time-horizon. Acedo & Jones (2007) in turn focus on the relationship between foreign-entry speed and entrepreneurs cognitive traits via Partial Least Squares (PLS). In particular, they find that foreign-entry speed is inversely related to entrepreneurs' perceived risk of international activity, where those risk perceptions are lower among entrepreneurs which are more internationally oriented (i.e. have international experience), tolerant of uncertainty, and pursue proactive business strategies. Finally, Zhao & Hsu (2007) employ hierarchical regression models on a sample of Taiwanese SMEs. Consistent with previously discussed findings, international experience shortens the formation-to-export time-span, as does the strength of social ties in the foreign market. Surprisingly, they find that firm size (value of assets) has a positive but insignificant effect on foreign-entry speed.

Given the scarcity of these explicit time-horizon analyses, it is not numerically surprising that productivity is only included as a determinant by few of them. Indeed, only Ilmakunnas & Nurmi (2010) employ explicit measures. It is however certainly surprising from a theoretical perspective – given trade theories' explicit reliance on productivity – until one realizes how under-explored firms' pre-export behavior, especially as it relates to timing, is theoretically.

## 2.2 Theoretical Framework

Like the empirical analyses discussed prior, the development of theoretical pre-internationalization models is a fairly recent development, whose underpinnings are

[1]Although interesting, these results are to be accepted more cautiously not only because of the rather small sample size (75 firms), but more importantly due the lack of developed measures of goodness-of-fit for ANOTA models (McNaughton, 2001)

primarily rooted in their "parent"-disciplines, Trade Theory (hereafter TT), and Internationalization Theory (hereafter IT), a field within international business. The brunt of theoretical models in both parent fields treat productivity very explicitly and a small subset of them do yield some prediction about time-horizon between firm-formation and export-initiation. However, these predictions are frequently more accurately understood as peripheral to the purpose of those models. Indeed, such peripheral treatment may be attributed to the perspectives on firm-behavior prevalent in IT and TT, neither of which inherently require attention be devoted to firms' pre-export behavior as a process explicitly operating through time (Ilmakunnas & Nurmi, 2010).

TT is generally more concerned with which firms export (e.g. Melitz, 2003; Melitz & Redding, 2014; Roberts & Tybout, 1997; Bernard & Jensen, 2004). IT on the other hand is primarily concerned with *internationalization* itself, the process in which firms expand their foreign economic activity through time (Johanson & Vahlne, 1977; Steinman, Kumar & Wasner, 1980; Amdam, 2009). However, the main approaches in this latter field, *Process-Based Internationalization Theory* (PIT) and *International New Ventures Theory* (INV), both are primarily concerned with the "pattern and pace" (Johanson & Vahlne, 1977, p. 23) of firms' internationalization – which begins with export-initiation as a first possible internationalization event – without similarly substantial theoretical development of that pattern and especially pace vis-à-vis the pre-internationalization period.

INV's subjects certainly are those firms which internationalize early in their lifecycle (Oviatt & McDougall, 2005; Bürgel et al., 2004, p. 6), and PIT's assumptions on firms suggests that their subjects are firms which internationalize late(r) in their lifecycle (Johanson & Vahlne, 1977, Bilkey & Tesar, 1977). Further, each approach generally contains a 'stage zero' – however short it is – in which firms are yet to undertake any export activity[2] (Johanson & Vahlne, 1977, Bilkey & Tesar, 1977, Oviatt & McDougall, 2005). However, a more appropriate conception of these treatments for our purposes is that they all fail to establish a theoretical approach to the pre-internationalization time-span itself. They instead use the boundary cases of foreign entry time-spans purely as a point of departure (Oesterle, 1997). Indeed, it may be argued that said stage zero is established purely to separate the location and entry-mode choices on first internationalization destinations – a central matter in IT (see e.g. Johansson & Vahlne, 1977, Bilkey & Tesar, 1977; Kusi, Gabrielsson & Kontkanen, 2021; Wiedersheim-Paul, Olson & Welch, 1978) – from the realized entry into those destinations.

Thus, the extant theoretical literature either treats primarily the post-export behavior (IT), or firms' formation-to-export behavior without regard for the time-horizon over which it occurs (TT). These historically different foci notwithstanding, recent literature has begun to assess the pre-internationalization time-span theoretically, and in particular with regards to its pace. Primarily, these treatments have

[2]With respect to the INV firm-archetype, this statement requires qualification. INV firms are defined by, once they have started producing, spreading that production quickly (internationalizing rapidly), and perhaps prior to that geographical distribution of production, distributing other parts of their operation (almost) immediately (Oviatt & McDougall, 2005). However, they are not inherently defined by having production distributed across locations in multiple countries from (or near) inception. In their original treatise, Oviatt & McDougall (2005) explicitly state that the representative INV is likely to initially concentrate production in locations which offer advantageous conditions. Further, even if such firms initiate exports fast, then it still appears reasonable that – whether the market in which production is geographically located is supplied or not – some time passes between firms' formation and initial export-activity. Thus, for our purposes, a stage zero exists if there is a non-zero time-span in which firms do not yet export and locate production in a single economy, however short it is.

been local theoretical extensions of IT-assumptions for the purpose of hypothesis development in empirical research, much in kind with ones made later in this paper. More recently however, Ilmakunnas & Nurmi (2010), hereafter IN, have proposed an extended export-participation model (based on Roberts & Tybout, 1997). Broadly speaking, export-participation models are applied discrete choice models in which firms' profit- maximization problem is characterized by the choice to supply the domestic market only, or both domestically and internationally (Roberts & Tybout, 1997; Baldwin & Gu, 2003). IN however expand on this approach. Admittedly, given the discrete-choice basis, INs' model describes the entry-export time-span only ex-post. It does however offer an explanatory vehicle which allows for the treatment of that time-span via an inherent 'drift' towards exporting, is consistent with behavioral assumptions on firms prevalent in IT models under mild modification, and allows for the formulation of hypotheses within a consistent framework.

INs' model specifically characterizes a firms' behavior as sequential export-initiation choices made in each successive period following firms' formation. The utility of their approach stems in particular from two key components relating to the principal profit-trajectory (costs and revenues), and to the treatment of uncertainty. Firstly, each maximization problem in the sequence is conditional on the expected profitability of the two choices – to supply domestically, or both domestically and internationally – in future periods (Ilmakunnas & Nurmi, 2010). In other words, it incorporates uncertainty over future costs, revenues, and the duration over which future profits occur. Secondly, the cost and revenue functions conditioning firms' choice problem are assumed to modify across periods. Through time, firms engage in learning processes in relation to both production and the nature of potential foreign markets prior to foreign entry (Ilmakunnas & Nurmi, 2010). Consequently, in the absence of adverse shocks or conditions, a given firm is likely to arrive at the profit-maximizing choice to export at *some* period after formation. Heterogeneity in the rate of learning and resource-investment further generate firms which may belong to the same formation-cohort, but initiate exports over different time-horizons (Ilmakunnas & Nurmi, 2010).

The fact that INs' model does not explicitly predict an entry-export time-span is unfortunate[3], indeed a problem frequently present in the larger IT literature (Bürgel et al., 2004, p. 6). However, their discrete-choice approach does offer some advantages. Firstly, it seems appropriate in that it roots the observed speed with which firms initiate exports in the choice-problem at the individual firm-level. Further, although IN propose a fundamental drift towards export-initiation, their formulation also very clearly permits adverse factors which depress the rate at which that drift occurs. Similarly, it is entirely possible that domestic (expected) profits occur such that, even given this drift, firms choose to supply domestically-only indefinitely. In this way, INs' model is not only consistent with the various mechanisms that may lead only a subset of firms to ever export (Wiedersheim-Paul, Olson & Welch, 1978; Melitz, 2003; Bernard & Jensen, 2004; Bernard, Eaton, Jensen & Kortum, 2003; Ilmakunnas & Nurmi, 2010), but it is consistent with those mechanisms in a way that roots them dynamically in the firm-level decision-process.

INs' export-participation model does however depart from IT in one crucial way. It does not establish risk-preferences, indeed (inadvertently) treats firms as risk-

[3]to the author's knowledge, such a model has not been developed formally (in a for our purposes useful manner) at the time at which this paper is written.

neutral[4]. Contrarily, virtually all IT approaches treat firms very explicitly as having such risk-preferences, with none of them generally proposing risk-neutrality. PIT approaches generally treat firms as risk-averse (Liesch, Welch & Buckley, 2011), while INV – which focuses on entrepreneurial, early internationalizing firms – conceives of firms as risk-seeking (Oviatt & McDougall (2000) in Liesch, Welch & Buckley, 2011). These opposing propositions are perhaps in large part a reflection of the firm-archetype PIT and INV treat respectively (Liesch, Welch & Buckley, 2011). Precisely because of this, it indeed seems that the opposition in their assumptions is reconcilable as it relates to risk-preferences.

The extension of IN here relies in principle on two assumptions[5]. Firstly, firms are fundamentally risk averse. Second, young firms are 'risk-ignorant'. Although (early) INV theory generally conceives of firms as risk-seeking – by virtue of being opportunity-seeking – this proposition may in fact be built on an incomplete behavioral understanding of entrepreneurs (Liesch, Welch & Buckley, 2011). Specifically, more recent research has found that these early internationalizers are not at all risk-seeking (Miller, 2007), but instead risk-ignorant (Liesch, Welch & Buckley, 2011; Hayward, Shepherd & Griffin, 2006). In other words, they are fundamentally risk-averse, but tend to overestimate their capabilities in the early years of their existence, which overrides choice in pure accordance with those risk-preferences (Hayward, Shepherd & Griffin, 2006; Simon, Houghton & Aquino, 2005). Then, as companies continue to exist and realize the true benefits and costs to their prior choices, their ignorance begins to dissipate (Liesch, Welch & Buckley, 2011). Intuitively, we can think of this as firms learning to be risk-averse through experience

Consequently, risk-aversion as it relates to firms' preferences may well be consistent with risk-seeking as it relates to observed behavior among INV firms. Such a proposition is also fundamentally consistent with firms' risk-minimizing choices concerning initial entry-mode (i.e. exports over FDI) and location (countries with low psychic distance) frequently assumed across IT approaches (Johanson & Vahlne, 1977; Bilkey & Tesar, 1977; Liesch, Welch & Buckley, 2011; Kusi, Gabrielsson & Kontkanen, 2021; Gallego, Hidalgo, Acedo, Casillas & Moreno, 2009). It should however be made very clear that the above proposition is not an attempt at fully reconciling PIT and INV approaches, indeed for that purpose it would be problematically insufficient. The proposed extension on IN purely serves to reconcile specifically firm behavior in relation to risk-preferences.

The broad utility of the proposed extension will become increasingly clear during the development of specific hypotheses in the subsequent section, but for now it allows us to supply a fruitful framework, on whose basis hypotheses are developed next: The time-span between firms' formation and initial export activity is fundamentally determined by the sequence of firms' export-participation choices (ex-post), where that choice is based on the probable (uncertain) profitability of exporting in

[4]To be precise: IN do not discuss this in their paper beyond that there is uncertainty. Their mathematical formulation however explicitly defines the choice-conditions as subject to uncertainty without containing risk-preference parameterization.

[5]It is however still a simplification. The interested reader may consult Liesch, Welch & Buckley (2011) for an excellent review of the internationalization literature concerning treatment of risk and uncertainty. They further propose a model which treats firms as having preferences over risk and uncertainty distinctly and interactively. Such a treatment is certainly interesting. However, like IT at large, their framework is concerned with internationalization overall more so than specifically pre-internationalization, and the extension of such a framework specifically onto the pre-internationalization time-horizon seems to require potentially highly complex assumption-sets. To not complicate matters further, such an extension of the theoretical framework is thus not made here.

the future. Expectations about profitability are informed by previous experience (including acquisition of knowledge on foreign markets), and choice is conditioned by firms' risk-preferences, specifically those preferences' natural evolution through time, and factors which modify risk-tolerance at any given point in time.

Finally, Wiedersheim-Paul, Olson & Welch's (1978) early work on firms' pre-export behavior should briefly be acknowledged. Their approach seems in principle compatible with the extended IN framework, and in particular supports the inclusion of non-neutral risk-preferences. Unlike IN however, their model does not supply any time-span component, and relies substantially on decision makers' cognitive orientation towards information related to international opportunities, i.e. how predisposed decision makers are to react to informational export stimuli (Wiedersheim-Paul, Olson & Welch, 1978). In essence, their work thus offers a qualitative version of an export participation model in which the inherent 'drift' towards exporting through time is not formally present. Since by their own admission, the realized behavior of firms which do and do not end up exporting may be quite similar, isolating the role of this cognitive orientation theoretically and empirically appears quite complicated.

More importantly, research suggests that indeed differences in perceptiveness to export-stimuli are a "significant but not sufficient condition for a positive export decision, and that important variations between exporters and non-exporters in cost, profit, and risk perceptions may well account for different responses to similar [export] stimuli" (Simpson & Kujawa, 2011, p. 107), lending additional support for the adoption of the risk-extended IN model. Finally, since this paper is ultimately empirically oriented, it makes local theoretical extensions purely for lack of established theory, and thus very carefully. In other words, it appears prudent to keep the magnitude of theoretical "leaps" to a minimum.

## 2.3 Hypothesis Development

### 2.3.1 Productivity

For our purposes, the key question then is how productivity affects firms' formation-to-export time-span. Taking a step back from productivity's impact on the time-horizon to export-initiation specifically, in much of firm-level trade theory productivity is an important (sometimes even *the*) determinant of whether a given firm initiates exports (Melitz, 2003; Melitz & Redding, 2014; Bernard et al., 2003; Roberts & Tybout, 1997; Aw, Robert & Xu, 2011). In these models, productivity frequently serves as the mechanism that allows firms to enter exports by overcoming the sunk cost barrier to foreign market entry immediately, or by permitting recovery of these entry costs post-entry, i.e. by exploiting scale economies not exhaustible under domestic demand (Haidar, 2012; Melitz, 2003). Assuming that firms develop productive capacities through time (learning), it thus appears reasonable that productivity is similarly an important determinant of the speed with which firms enter a first foreign market. This proposition seems appropriate in particular because learning processes, and thus productivity gains, are a core determinant of firms' internationalization-speed in IT models (Johanson & Vahlne, 1977).

Across process-based IT, this is clearly the case. Firms' activities at any point in time are conditioned by the knowledge acquired up until said point (Johanson & Vahlne, 1977). Since the acquisition of new knowledge not only modifies the extent but also form of resource commitment to foreign activity (Johanson & Vahlne, 1977; Steinman, Kumar & Wasner, 1980; Amdam, 2009; Blomstermo, Eriksson & Sharma, 2004), it seems straightforward to assume that the state of knowledge acquisition, specifically learning in relation to production technique(s) and/or technology, determines the efficiency with which production is undertaken (Ilmakunnas & Nurmi, 2010). In other words, the acquisition of production-knowledge, once integrated into the production process, may be understood as firms' productivity.

Further, the pace of international expansion that firms are willing to take on is assumed to increase in the stock of (physical and knowledge) resources at their disposal by raising risk-tolerance (Johanson & Vahlne, 1977). In other words, by raising firm's risk-tolerance, increased knowledge increases the magnitude of international expansion those firms undertake within a given time-interval (Johanson & Vahlne, 1977). Since this assumption is rooted in the risk-preferences of firms (their risk-aversion), and since there is no a priori reason to assume that these preferences are fundamentally divergent between the internationalization process and the process leading up to it, we may generalize these risk-related preferences. Specifically, since risk-tolerance is assumed to be modified by knowledge at firms' disposal, and thus productivity via "production learning" (Ilmakunnas & Nurmi, 2010, p. 106), it appears reasonable that high(er) productivity raises the risk-tolerance to initial international activity at any point in time. Putting this in terms of INs' export-participation model, high(er) productivity increases the rate at which the drift towards export-initiation is realized, enabling firms to enter foreign markets more quickly (Ilmakunnas & Nurmi, 2010). Thus, all else being equal

*h(1) firms' time-horizon between formation and initial export activity is decreasing in their productivity*

However, even if higher productivity observationally significantly shortens the time-horizon to initial export activity (Ilmakunnas & Nurmi, 2010; Bürgel et al.[6], 2004, p. 149), this proposition nonetheless requires qualification. For lack of a frame of reference, newly founded firms (i.e. the INV firm-archetype) may lack an accurate assessment of their productivity, developing such only through experience (Olley & Pakes, 1996). Thus, productivity advantages may not be consciously important in the decision process of newly founded firms (Bürgel et al., 2004, p. 96). Even so, if a newly formed firm does not correctly attribute its ability to e.g. recover foreign-entry sunk costs to its productivity, then it will still base its ability to do so on perceptions of its capabilities (Durand, 2003). Those capabilities (judged by a firm for example by its more tangible profits) in turn will in part be a consequence of firms' productivity. Indeed, this relationship between capabilities (profitability) and productivity is what defines firms' choice (profit-maximization) problem in much of firm-level trade theory (Melitz, 2003).

Thus, although this qualification does not affect the above hypothesis vis-à-vis the relation between productivity and the formation-to-export time-span, it does offer an interesting perspective on the nature of productivity's importance in firms' decision process. It should further be emphasized that the effect of procuctivity relates specifically to production learning, i.e. knowledge which upon acquisition

[6]They 'only' include investment into R&D and the intensity of such investment, which for various reasons seem sub-optimal instruments (see e.g. Oesterle, 1997), although given that data used is obtained from surveys and interviews, the generation of consistent productivity measurements may have been problematic.

modifies how firms produce a good, and not 'market learning'. This distinction is important, because knowledge acquired about the institutional and demand characteristics of a foreign market which has not yet been entered is mechanically unlikely to modify firms' productivity.

### 2.3.2 Ancillary Hypotheses

**Physical Resources**[7] In turn, propositions concerning the effect of firms' accumulation of, and investment into physical resources on the formation-to-export time-span are quite consistent across IT approaches. Indeed, the principal argument rests on the same two propositions which (partly) inform the hypothesized relationship between that time-span and firms' productivity. First, the pace of internationalization that firms are willing to take on increases in the stock of resources at their disposal, because it raises the risk-level firms find tolerable (Johanson & Vahlne, 1977). Second, assuming firms' risk-aversion is not developed only after foreign entry, then all else being equal, the speed with which firms initiate exports in the first place is increasing in the accumulation of those same resources.

Indeed, in this regard the proposed relationship is not unique to the traditional IT firm-archetype. Risk-tolerance towards activities that are new to a firm, and whose utility it thus cannot judge from experience - such as first-time export-initiation - tends to be increased by activities that firms perceive to enhance capabilities (George, Chattopadhyay, Sitkin & Barden, 2006). In particular, investment into (physical) resources has been found to function in this way (Durand, 2003). Thus, investment appears particularly relevant for young (i.e. INV) firms, as they not only necessarily lack experience in foreign activity, but also inherently have very limited operational experience (as a company) at large. Consistent with previous empirical findings (Ilmakunnas & Nurmi, 2010; Bürgel et al., 2004, p. 149; Zhao & Hsu, 2007), this implies that

*h(2) firms' time-horizon between formation and initial export activity is decreasing in the size of their labour stock*

*h(3) firms' time-horizon between formation and initial export activity is decreasing in the size of their investment into physical capital*

**Age and Time of Formation** Firms' willingness to take on risk more fundamentally instead does not yield intuitive hypotheses. Although the theoretical extension of INs' export-participation model proposed earlier permits insight into the role of risk-perception, and in particular how risk-taking is modified by certain firm-level activities, this does not lead to straightforward predictions about how those risk-preferences, and relatedly, experience affect firms proclivity to initiate exports at different points in their lifetime. Although the rate at which firms acquire experience (which does not directly translate into productivity adjustments) may be difficult to explicitly integrate empirically, it nonetheless appears reasonable to assume that experience increases with firms' age.

[7] Although not the principal focus of this paper, various firm-characteristics which empirically enter (purely) as controls are discussed here as well. This in particular appears necessary given the limited previous research and thus importance of justifying those covariates which are employed.

As established previously, fundamentally risk averse firms may initially behave as though they are risk-seeking, increasingly acting in accordance with their risk-aversion only as experiences prove their cognitive bias unwarranted (Liesch, Welch & Buckley, 2011; Hayward, Shepherd & Griffin, 2006). All else being equal, this may lead us to believe that firms are decreasingly prone to initiate exports the longer they exist, an argument that may be consistent with INV, but not with PIT. Conversely, in the same way in which production-learning (thus productivity) positively affects firms' risk-tolerance at any point in time, the accumulation of experience is assumed to raise the risk-tolerance of firms (Johanson & Vahlne, 1997). As this is one of the key drivers of firms' internationalization pace in process-based IT, it would lead to the proposition firms' willingness to initiate exports the longer they have existed domestically.

In addition to these opposing perspectives, there are two more fundamental aspects that require careful consideration. Firstly, as opposed to analyses of firms' internationalization time-span, firms' age is mechanically problematic when one's interest is in the time elapsed between a firm's formation and its initial internationalization event, because for our purposes that time-span is firms' age. Further, it is not obvious that the opposition in process-based and INV approaches reflects the coexistence of two fundamentally different firm types. While it is certainly the case that some firms are more 'entrepreneurial' than others, INV, like process-based approaches preceding it, was informed by the dominant internationalization pattern at the time. In this sense, it seems entirely possible that the assumed behavior of firms is a reflection of prevalent industry characteristics at the time, i.e. the degree of economic integration. Thus, as we observe different cohorts of firms it is entirely possible that we observe both firm-archetypes within an industry (McNaughton, 2001). Consequently, it appears reasonable to assume that

*h(4) the later a firm forms (in calendar time), the shorter is its time-horizon until initial export activity*

# 3. Data and Variables

## 3.1 Data

To identify the impact of productivity on the length of firms' formation-to-export time-span, this paper draws on a sample of French manufacturing firms in the fabricated metal products industry (as classified by NACE Rev. 2 at the 2-digit industry level), containing firm-cohorts born between 1995-2019[1]. Besides technical concerns related to the availability of specific variables, this paper's focus on a single country, and single manufacturing industry is primarily driven by theoretical and methodological concerns.

First and foremost, although PIT and INV respectively prescribe very different characteristics, both historically focus on, or are derived under consideration of manufacturing firms (e.g. Johanson & Vahlne, 1977; Oviatt & McDougall, 1995; Bilkey & Tesar, 1977). Given the necessity for the local theoretical extensions made earlier, it thus seems prudent to focus on an industry which adheres to the theoretical sentiment said extensions are drawn from. Second, although a comparative perspective is certainly of interest (Rialp, Rialp & Knight, 2005), such analyses are complicated by the fact that a given measure of productivity is not inherently equally applicable across industries, or robust to differences in data-quality between countries (Gal, 2013). The focus on a single industry is thus in large part a means to reduce heterogeneity in unobservables and consistency in the measurement of observables. Consequently, comparative analyses are left for future research.

With this in mind, the sample employed is drawn from Bureau van Dijk's ORBIS database (BvD, n.d.). Obtaining consistent longitudinal measurements of firms' characteristics – in particular, characteristics relevant to construct productivity measures – is inherently a complicated endeavor. Generally, firms are legally required to supply relatively granular, and frequent information on their revenues, costs, and investments to their respective governments for tax-purposes, but such annual account data (balance sheets and profit/loss statements) are not easily accessible. ORBIS in this respect offers the advantage that it continuously compiles firms' annual accounts from governmental sources, either directly or through intermediaries (Ribeiro, Menghinello & De Backer, 2010; Kalemli-Ozcan, Sorensen, Villegas-Sanchez, Volosovych & Yesiltas, 2015).

It should however be emphasized that this data by no means constitutes an

[1] The choice of time-horizon is motivated by the following concerns: The lower bound (1995) is chosen because prior coverage of firms is problematically sparse both in number of firms observed, and the completeness of data for observed firms. The upper bound (2019) in turn is chosen for three reasons. Firstly, observations of firm data enter ORBIS with a time-lag of approximately two years. Secondly, (presumably due to the pandemic) data for most variables is completely absent for the majority of firms between 2020-2022. Finally, industry- and variable-specific price indices are only available until 2019.

'optimal' sample. ORBIS, like most firm-level data, is prone to sampling bias. The specificity with which firms file annual accounts – i.e. the extent to which they have to disaggregate their cost and revenue streams – is generally tied to their performance. For example, although all French companies are required to file at least rudimentary annual accounts (Kalemli-Ozcan et al., 2015), companies with with turnover below certain thresholds are not required to file complete annual accounts (PwC, 2012). Consequently, it is probable that larger (in turnover and employees) firms are both disproportionately represented in ORBIS, and that smaller firms are more frequently excluded empirically even if observed, because their data is too incomplete (Ribeiro, Menghinello & De Backer, 2010). In other empirical settings we can normally account for this via stratified sampling or by weighting individual firms' in the empirical model according for example to their size based on a known size-distribution (Gal, 2013). Despite the various advantages that duration models offer, one important drawback is that such strategies to enhance representativeness become substantially less straightforward[2]. Thus, bearing in mind that its findings are likely to be less representative of small and micro-firms, this paper reluctantly satisfices with the unbalanced sample.

## 3.2 Variables

**Productivity** Firm-level productivity is captured via labour productivity. While labour productivity is widely employed (Bürgel et al., 2004, p. 172) this paper in particular bases labour productivity on firms' value-added, i.e. revenue less cost to intermediate inputs and resold goods (Gal, 2013). Specifically, firms' productivity is then obtained as

$$LP_{i,t} = VA_{i,t}/L_{i,t} \tag{3.1}$$

where $VA$ and $L$ are a firm's value-added and number of employees, respectively. In principle, labour productivity can similarly be obtained using firms' gross output (revenue), but this poses two problems. First, as opposed to value-added based labour productivity, gross-output based labour productivity does not control for firms' utilization of immediate inputs (Gal, 2013). Secondly, missing observations for value-added can be imputed internally, while the same is not the case for gross output. In particular, to minimize loss of firms to missing data, this paper follows Gal (2013), imputing value-added as the sum of firms earnings before interest, taxes, depreciation, and amortization (EBITDA), and employee costs. This results in a net gain of approximately 5.200 individual observations[3]. To verify the appropriateness

[2]For intuitiveness' sake I strongly recommend the reader returns only once they have read the methodology section. The difficulty in improving samples' representativeness in duration models without loss of information lies in the fact that duration models require data which exists in calendar time, but which is normalized into relative time. By example: given two firms, one formed in 2010 and one in 2015, the structure of the data must be adjusted such that both firms and all its characteristics (covariates) enter observation at relative time $t = 0$. Only once the data is prepared in this way can duration models be employed. While it is technically possible to supply weights to duration models, it is no longer straightforward to design them. Since time is made relative, popular weighting procedures based for example on the size-distribution of firms (Gal, 2013) are complicated by the fact that firms at each relative point in time do not exhibit a joint size-distribution (because such distributions exist, if available, in calendar time).

[3]Only 38 individual observations for value-added are lost by using imputed over reported value-added

of the imputed values, correlations between known and corresponding imputed values are obtained for each calendar year, resulting in an average correlation of 0.98, significant at $p < 0.01$ for all individual years (see appendix A.1 for annual correlations). To ensure consistent measurement, imputed value-added is thus employed in the calculation of labour productivity for all firms (Gal, 2013).

It should be noted, that from a theoretical perspective, measures of total factor productivity are preferable since they do not condition productivity measurement on a single production input: Labour (Gal, 2013). Unfortunately, such measures are not viable given the available data. First and foremost, these measures are in large part estimation-based and pose substantially larger data requirements and/or harsh assumptions that are unlikely to hold (Aw & Hwang, 1995; İmrohoroğlu & Tüzel, 2014; Jovanovic, 2018), resulting in a problematically high loss of sample size and exacerbating the selection bias of larger firms. Additionally, the methodologically more appropriate techniques (e.g. Ericson & Pakes (1995), Levinsohn & Petrin (2004), or Wooldridge (2009)) require lagged estimation inputs which is not unproblematic since we require productivity be known at/near firms' formation[4]. To partially alleviate the potential bias induced by using labour productivity, capital-intensity – the ratio of physical capital to labour employed – is added as a control, but that is admittedly an imperfect solution[5] (Bürgel et al., 2004, p. 172).

**Physical Resources** Controlling for firms' accumulation of resources in regards to size of the labour stock ($h(2)$) is straightforward, as firms' number of employees is directly obtainable. However, the appropriate measurement of firms' physical capital (machinery and equipment) hinges on additional considerations. Physical capital is not only required to control for firms' relative input usage via capital-intensity, but also to control for firms' investment into physical capital more generally ($h(3)$). In principle, the book value of firms' fixed tangible assets can be employed to this end (Gal, 2013). However, this does not account for depreciation (i.e. the decay of machinery) and consequently overestimates the physical capital available to firms. Thus, this paper instead follows generally accepted practice, obtaining firms' capital and investment by means of Perpetual Inventory Method (following Gal, 2013; see also: Chen & Plotnikova, 2014), which defines firms' capital at each time $t$ as

$$K_{i,t} = K_{i,t-1}(1 - \delta_{i,t}) + I_{i,t} \tag{3.2}$$

where investment $I_{i,t}$ is defined as

$$I_{i,t} = (FTA_{i,t} - FTA_{i,t-1} + D_{i,t}) / PI_t \tag{3.3}$$

Here, $FTA_{i,t}$ is the book value of fixed tangible assets, $D_{i,t}$ the monetary value of depreciation, $\delta_{i,t}$ the rate of depreciation and $PI_t$ the investment price deflator. In a firms' first 'period' of existence, depreciation and lagged capital stock are necessarily zero, such that in that period calculation simplifies to $FTA_{i,t}/PI_t$, i.e. investment

[4]Specifically, lagged values of estimation inputs in firms formation-period are necessarily 0, and thus variation in a given estimation-input is not given.

[5]It should nonetheless be highlighted that labor productivity does not measure the contribution of labor to production, but instead relates the productivity of a firm to labor as a common benchmark (Kask & Sieber, 2002).

and capital stocks are equivalent at firms' time of formation. While the calculated capital stock and investment obtained in this way offer a substantial improvement over directly using the book value of fixed tangible assets, it is by no means a perfect measurement. Physical capital is by definition a catch-all for different physical production inputs which depreciate at different rates (Chen & Plotnikova, 2014). It is rarely possible to obtain firm-level data granular enough to differentiate physical capital subsets to account for such differences, and ORBIS is no exception. This paper nonetheless follows Gal (2013) in defining the depreciation rate $\delta_{i,t} = D_{i,t}/FTA_{i,t-1}$, such that the rate of depreciation is increasing in the size of physical capital.

**Industry-Level Controls** Although the previously discussed variables offer reasonable controls to isolate the effect of specifically firms' productivity at the firm-level, firms' perceptions of the profitability of initiating exports and thus willingness to do so similarly hinge on their market environment (Ilmakunnas & Nurmi, 2010, Powell, 2014, McNaughton, 2008). To account for such environmental characteristics, the lagged volumes $(t-1)$ of domestic supply and domestic supply to the export market are included as industry effects at each time $t$. Domestic supply volume is obtained as total domestic output less export volume to isolate supply to domestic markets. While previous literature (Ilmakunnas & Nurmi, 2010) employs real GDP to account for cyclical effects in the home-market, it appears preferable to account for such effects directly in the export and domestic segments of the industry.

To capture more explicitly the competitive nature of markets, metrics such as the Herfindahl–Hirschman Index (HHI) are theoretically preferable (Powell, 2014). However, obtaining the HHI requires sufficiently complete measurement of the number of firms in the domestic and export market as well as their market shares, which cannot reasonably be obtained from the available data (or, to the author's knowledge, from external sources). For this reason, the first lag of the Grubel-Lloyd Index (GLI) is employed as an additional industry-level control. Proximately, the GLI measures the intensity of intra-industry trade, i.e. the relative magnitude of simultaneous exports from and imports into a country within one industry (van Marrewijk, 2017, pp. 180-1; Widodo, 2009). Mathematically, the GLI is obtained as

$$GLI_t = 1 - \frac{|X_t - M_t|}{(X_t + M_t)} \in [0, 1] \tag{3.4}$$

where $X_t$ is the volume of exports, $M_t$ the volume of imports, and thus $(X_t + M_t)$ and $|X_t - M_t|$ are the total volume of intra-industry trade and the absolute difference between exports and imports, respectivily. The GLI thus obtains the extent to which an industry (in a country) simultaneously exports and imports a good, with values closer to 1 indicating high level of intra-industry trade (van Marrewijk, 2017, pp. 180-1)

Fundamentally however, the existence of intra-industry trade is a characteristic of industries whose individual firms produce differentiated goods, which respond to consumers' demand for variety in those goods, and where that demand for each variety is conditional on individual firm's prices (Van Marrewijk, 2017, pp. 192-193). Consequently, the GLI may be understood as an implicit measurement of the competitiveness (and diversification) of firms in the export-market. However, a given country normally measures exports and imports in different ways. While export value is usually measured to account only for costs borne by firms themselves, the same is not the case for imports (Widodo, 2009). As pointed out by Widodo (2009), the former measurement unit is preferable, and so this paper follows their procedure to obtain comparable export and import values. In particular, an adjustment coefficient is obtained as $\alpha_t = \frac{X_t}{M_{reported,t}}$, by which the observed value of imports is normalized ($M_t = \frac{M_{reported,t}}{\alpha_t}$) before it enters into GLI calculation.

Finally, to account for firms' formation time, their formation-year can be directly obtained from ORBIS. To make observations of variables at different points in time comparable, nominal export, import and domestic production volumes at the industry-level are further deflated using industry-specific output price-indices, following best practice (Gal, 2013). Similarly, value-added and investment are deflated using respective industry-level price-indices[6]. Industry-level export, import and domestic production volumes, as well as price indices are obtained from OECD's STAN, iSTAN and BTDIxE databases (OECD, n.d.a-c). Further (following Ilmakunnas & Nurmi, 2010) the natural logarithms of all predictors – excluding the GLI and formation year – are taken, which later enter into the empirical model. Summary statistics are displayed in TABLE 3.1 below.

**Table 3.1** Summary Statistics, 1995-2019 (pooled)

| Variable | min. | mean | median | max. |
|---|---|---|---|---|
| *Firm-Level* | | | | |
| log labour productivity | 5.92 | 10.69 | 10.70 | 15.99 |
| log capital intensity | 0.02 | 8.75 | 9.05 | 19.66 |
| log no. employees | 0.69 | 1.46 | 1.10 | 7.03 |
| log investment | 0.000 | 8.65 | 9.14 | 18.07 |
| formation year | 1995 | 2007 | 2007 | 2019 |
| *Industry-Level* | | | | |
| GLI | 0.61 | 0.78 | 0.77 | 0.99 |
| log export supply volume | 8.9 | 9.62 | 9.69 | 10.04 |
| log output supply volume | 10.29 | 10.47 | 10.44 | 10.68 |
| No. of observations | 2862 | | | |

GLI: adjusted Grubel-Lloyd Index

Source: own calculation on ORBIS-data (BvD, n.d.)

[6] To ensure consistent measurement, price indices are chosen or modified to share a common reference year (2015). Notice further that export, import, and domestic output data are originally available only in current US$, and are thus converted into local currency prior to deflation (using OECD, 2024).

# 4. Methodology

## 4.1 Econometric Approach

The effect of productivity on the formation-to-export time-span is analyzed empirically via duration models. It is certainly possible to directly record the length of that time-span, and introduce it as a dependent variable in other quantitative approaches (Bürgel et al, 2004, p. 142). Bearing in mind however, that this requires a sample restricted to firms already observed to initiate exports, such alternative approaches are unlikely to yield particularly accurate results with regards to the true importance of firms' productivity. In particular, such an approach implicitly entails the rather strong assumption that firms which are not observed to initiate exports do not belong to the population of interest. Consequently, it is probable that firms which initiate exports at later points in their lifetime are under-represented.

Duration models do not suffer from this, as their formulation allows for the inclusion of firms which form at different points in calendar time. This is achieved by restructuring firms observed in calendar time such that all firms enter observation at relative time $t = 0$. More importantly, firms whose export-imitation is not observed during the (calendar) study time can be included. Formally, the latter is referred to as *right-censoring* (Clark et al., 2003a; Yang & Aldrich, 2012; Zhang, 2019). Amongst other reasons, this is precisely why duration models are preferable for our purposes. In particular, duration models operationalize two objects, $H(t)$, a conditional probability distribution of events (export-initiation) over time, and an exponentiated term containing predictors and related estimators which modify said event-distribution (Bürgel et al, 2004, p. 145). Mathematically, this leads to the general formulation

$$H(t|X_{i,j}) = H(t)\exp(\beta_1 X_{i,1} + ... + \beta_j X_{i,j}) \tag{4.1}$$

The first of these two elements, the conditional probability distribution $H(t)$ is obtained from two probabilistic quantities, the hazard rate $h(t)$ and the survival rate $s(t)$ (Clark et al., 2003a). The empirical estimation of $h(t)$ is quite complex since censoring occurs, such that the observed distribution of export-initiation times is incomplete (Clark et al., 2003a). Assuming however for explanatory purposes, that all export-initiation times are known, intuitively it suffices to approach $h(t)$ and $s(t)$ in terms of the distribution functions they are mathematically equivalent to (Bürgel et al, 2004, p. 143). In particular, let $f(t)$ be the unconditional probability that a firm is exporting at a given time $t$, and the survival rate $s(t)$ the probability that a firm is not exporting at that time (Clark et al., 2003a; Bürgel et al, 2004, pp. 143-4). Integrating (or summing) over $s(t)$ we obtain the distribution $S(t)$, which yields the proportion of firms which have initiated exports by time $t$ (Clark et al., 2003a; Bürgel et al, 2004, pp. 143-4). So far, this is unproblematic since $f(t)$, $s(t)$ (and thus $S(t)$) are observable. While the hazard rate $h(t)$ is not directly observable, mathematically it is equivalent to the ratio $f(t)/S(t)$. It is thus a conditional probability distribution function, specifically the probability that at a given time $t$, a firm initiates exports conditional on not having initiated exports at any prior time since its formation ($t = 0$) (Clark et al., 2003a; Bürgel et al, 2004, pp. 143-4).

Our interest is however not simply in the hazard rate at a specific time, say, five years after firms are formed. Instead, to obtain the effect of productivity on the set of $k$ possible formation-to-export time-spans ($k = 1, ..., K$), we require the cumulative hazard function which, assuming for simplicity that $h(t)$ is discrete (Bürgel et al., 2004, p. 145), is

$$H(t) = \sum(h(t_k)) \tag{4.2}$$

This is precisely the conditional probability distribution of interest (Bürgel et al, 2004, p. 145). In eq. 4.1, $H(t|X_{i,j})$ is thus the hazard function which is conditional on both time and time-dependent covariates, which by $\exp(\beta_1 X_{i,1} + ... + \beta_j X_{i,j})$ are defined as in a (in exponentiation) linear relationship with the hazard-rate (Therneau, Crowson & Atkinson, 2024). The chief difference between different duration models is then in the assumptions made about the distribution of $H(t)$ in particular given the existence of firms whose export-initiation is censored (Bürgel et al, 2004, p. 144). However, before the specific duration models employed in this paper are discussed, it is at this point important to address key assumptional requirements underlying them all.

**Event Definition** First and foremost, the time-horizon and event of interest must be well-defined. For our purposes, the event-of-interest is the first time a firm initiates exports. Thus, the time-horizon of interest is defined as strictly left-bound by firms formation-time, and open to the right at the time at which a firm initiates exports or is right-censored. Notice that all firms are right-censored at the end of study-time, unless they initiate exports before that time.

**Event Independence** Second is the requirement that individual firms' export initiation times are independent of each other, since otherwise $H(t)$ cannot be properly defined (Clark et al., 2003a). While it can not be ensured that strict independence is satisfied (i.e. events are unconditionally independent), the more frequently invoked assumption that events are conditionally independent, i.e. that firms' export initiation is independent of other firms' timing once dependencies are accounted for by the present covariates, appears reasonable (Wolbers, Koller, Stel, Schaer, Jager, Leffondré & Heinze, 2014).

**Non-informative Censoring** Third is the requirement, that firms which exit observation without initiating exports are right-censored non-informatively. Intuitively speaking, this means that right-censoring is not caused by some circumstance which modifies firms' likelihood to initiate exports after they are right-censored (Clark et al., 2003a).

With these assumptions in mind, this paper follows Bürgel et al. (2004, p. 144), employing in particular three model specifications, the Cox Proportional Hazards (CPH), Weibull, and Exponential model. The Cox Proportional Hazards model is most widely employed across disciplines. Its chief advantage is that it estimates $H(t)$ non-parametrically, which in particular means it does not make assumptions about the distribution of $H(t)$, instead estimating such from the observed distribution of export-initiation times under consideration of right-censored firms (Clark et al., 2003a). It does however operate under the *proportional hazards assumption*, the assumption that the effect of a given covariate is constant across firms at a particular time $t$ (Clark et al., 2003a; Park & Hendry, 2015).

In turn, the Weibull and Exponential model are more flexible in that they do not require the proportionality assumption. They are however parametric and thus make distributional assumptions about the shape of $H(t)$, although parameters are estimated from the observed data and thus still flexible (Clark et al., 2003b). In particular, the Weibull model assumes that $H(t) = \alpha\gamma t^{\gamma-1}$, where $\alpha$ and $\gamma$ are parameters fitted to the distribution. $\alpha$ is a non-negative scale-parameter, where $H(t)$ is assumed to increase if $\alpha > 1$, and decrease if $\alpha < 1$. $\gamma$ in turn is a distribution-shape parameter. In other words, $\alpha$ determines whether firms are more or less likely to initiate exports the longer they exist without having exported, and $\gamma$ determines the density of export-initiation events at different points in time (Rodríguez, 2007b; Bürgel et al., 2004 p. 144). In turn, the Exponential model is a specification of the Weibull model, in which $\gamma = 1$, i.e. it makes the assumption that the hazard rate is constant through time, or intuitively speaking, that export initiation occurs at a constant rate through time (Rodríguez, 2007b; Bürgel et al., 2004, p. 144).

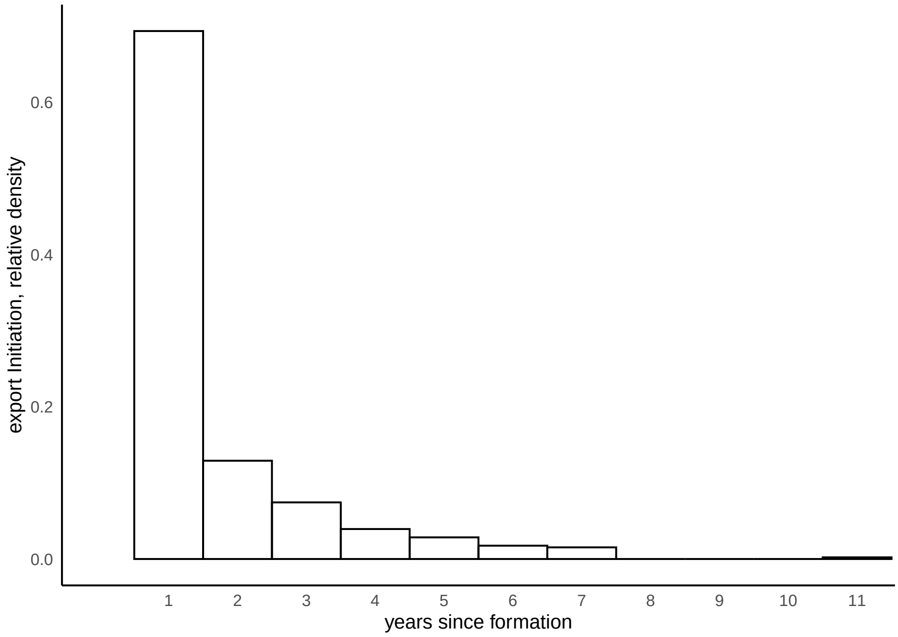
Intuitively speaking, the Weibull and Exponential model are thus appropriate if $H(t)$ is always declining or increasing, although the Weibull model permits variation in the magnitude of that decline (Clark et al., 2003b). Notice further, that since time-varying covariates are employed, the estimated conditional hazard function $H(t|X_{i,j})$ may not appear to satisfy the Exponential model's constant hazard function. This assumption is strictly on $H(t)$ itself. As can be informally inferred from the distribution of export-initiation times (see Figure 4.1), both Weibull and Exponential models thus seem appropriate[1].

Further, the fact that observations are only available annually must be taken into account. Formally, the data is thus *interval censored*: Firms' characteristics and their export status at any point in a given year are only observed at the end of that year. Consequently, the model specifications employed are modified to treat time in discrete intervals, permitting correct interpretation (Ilmakunnas & Nurmi, 2010). We should further note, that while for the CPH model coefficients are commonly reported in expoentiated form, for the purpose of simplified comparison this paper instead directly presents coefficients, such that positive values can be understood as a unit increase in the associated covariate raising the export-initiation likelihood through time (or one-percent increase in the case of logged covariates), and thus by inference shortening the formation-to-export time-span.

Finally, given the particular characteristics of duration models, sampling and

[1]The distribution similarly disqualifies log-logistic or log-normal model specifications, which are appropriate only when the distribution peak is not located at either distribution tail (Clark et al., 2003b)

**Figure 4.1** Distribution of Observed Export-Initiation Times




Source: own calculation on ORBIS-data (BvD, n.d.)

censoring conditions require additional attention[2]. To obtain reliable estimates, various measures to restrict the sample are employed. Chief amongst them is that left-truncated and left-censored firms do not enter the sample. *Left-truncation* occurs when firms' formation-time is known, but they only enter observation at a later point in their life-time, while *left-censoring* occurs when a firm is observed since formation but its export-status is unknown for some time following their formation (Clark et al., 2003a; Aldrich & Yang, 2012). In other contexts this can certainly be accounted for. However, strictly speaking, we cannot know if a firm initiated exports already if we do not observe its export-status from formation. This seems particularly problematic since most firms initiate exports quite early after they are formed, as is observable in Figure 4.1. Consequently, It appears prudent to restrict the sample only to firms whose export-initiation timing can be pin-pointed.

Relatedly, it frequently happens that observations of firms' export status are temporarily interrupted. Since, as with left-truncation, it cannot be established whether a firm initiated exports during the temporarily unobserved time-span, this is problematic. This paper's approach in this regard follows Ilmakunnas & Nurmi (2010). Specifically, firms whose interruption does not exceed one year are treated as though the event did not occur, and retained in the sample. While this is methodologically not desirable, eliminating firms with single-year interruptions is also likely to bias results against firms which initiate exports later in their lifetime. In an alternative specification, firms are thus only retained until the first time their export-status is no longer (even if only temporarily) observed. This results in a sample size of 2.862 firms under less strict censoring, and 2.856 firms under strict censoring conditions, respectively. It is thus not expected that the two specifications yield substantially

[2]The rather complex restructuring that must be undertaken to make data deployable for duration analyses is not discussed here. The interested reader is referred to Singer & Willett (1993), whose approach is consistent with the demands that statistical duration model packages generally require given time-varying covariates, and which is thus adopted here.

different results, but the strict censoring condition is nonetheless employed as a robustness check.

A final methodological issue concerns the relationship between the formation-to-export time-span and covariates. Since firms are assumed to make deliberate choices, and thus choices are conditioned by firms' characteristics (covariates), it is probable that those covariates are not strictly exogenous. However, at each point in time, firms' choices – as regards what is captured by covariates – are conditioned only by present and past observations, such that the observed formation-to-export time-span and covariates are sequentially exogenous (Ilmakunnas & Nurmi, 2010)

## 4.2 Limitations

At this point, it appears prudent to emphasize the various limitations which this paper's quantitative analysis is subject to. In addition to the various limitations on the accuracy of variables discussed prior, there are equally methodological concerns that warrant attention. Most important amongst them is the appropriateness of the non-informative censoring assumption.

Indeed, non-informative censoring cannot be satisfied, because firms may exit the market (i.e. become bankrupt). Market-exit thus constitutes a *competing event*. Formally, two (or more) events are competing if, and only if they are mutually exclusive over the time-horizon of interest (Legrand, 2021, p. 213; Wolbers et al., 2014). In this sense, market-exit constitutes a clearly competing event. In particular, if a firm exits the market before initiating exports, its export-initiation probability necessarily turns zero. Under such conditions, a (single-event) survival model generates upward-biased survival estimates (Manzoor, Adimadhyam & Walton, 2017; Wolbers et al., 2014; Therneau, Crowson & Atkinson, 2024). Strictly speaking however, this is not 'merely' an issue of precision. In the presence of competing events, the event-probabilities at each point in time - and their time-path - are no longer properly interpretable, (Legrand, 2021, p. 215; Rodríguez, 2007b). Intuitively speaking if competing risks are not accounted for, any interpretation implicitly operates under the assumption that firms which no longer exist still have a non-zero probability to initiate exports (Legrand, 2021, p. 218; Wolbers et al., 2014).

Unfortunately, ORBIS data does not lend itself to competing-risk analyses. While firms' export status can be directly obtained at each observed point in time, the time at which a firm exits the market in most cases can only be approximated. More importantly, it is not generally the case that export status is observed until the approximated time of market-exit. In other words, firms tend to become right-censored with regards to their export status before they are observed to exit the market. Since market-exit as a competing event cannot be accounted for, an alternative strategy is adopted. Specifically, estimation is undertaken *naïvely*. Firms which are right-censored due to market-exit are treated as though censoring occurred non-informatively. Thus, the resulting estimation is (must be) interpreted as based in a hypothetical scenario in which market-exit does not exist (Andersen, Geskus, de Witte & Putter, 2012). It should however be emphasized, that for the reasons discussed prior (bias and interpretability), this is not desirable, and thus estimation results are to be accepted cautiously.

Finally, a more complex issue emerges with the inclusion of right-censored firms. Duration models are normally able to include, and estimate from censored data, because they are formulated under the assumption that all units of observation will experience the event of interest at some point, even if not observed (Amico & Van Keilegom, 2018; Legrand, 2021, p. 153). However, this is a complicated assumption in regards to export-initiation. The theoretical framework informing this papers' empirical analysis implies that, unless exogenously conditioned otherwise, all firms will eventually initiate exports (Ilmakunnas & Nurmi, 2010). Nonetheless, this result is a consequence of mathematical construction, and may thus be insufficiently satisfactory. Although adjusting for firms which never export is certainly possible by means of a *cure model* (a modification of duration models, see e.g. Amico & Van Keilegom (2018), and Legrand (2021, pp. 158-175)), such cannot yield appropriate results if the competing risk of market-exit is not adjusted for as well. Consequently, this point is made here primarily to inform future research, and more importantly, to make very aware of the limitations of this paper's empirical approach.

# 5. Empirical Analysis

## 5.1 Results

Estimation results are displayed in Table 5.1. The directionality of covariates is entirely consistent across the CPH, Weibull, and Exponential models. Firms' probability to initiate exports is positively related to productivity, number of employees, and investment into physical capital. It is similarly positively associated with firms' formation-year, implying that firms that are more productive, employ more labour, undertake larger investment into physical capital, and firms 'born' more recently tend to initiate exports faster. Conversely, capital-intensity appears to have a negative association with the probability to initiate exports, implying that firms which rely relatively more on capital than labour enter export markets more slowly. At the industry level, the lagged volumes of both export-market supply and domestic supply appear to negatively affect the speed with which firms initiate exports. In turn, more intense intra-industry trade (as measured by the GLI) appears to shorten the time-span between firms formation and initial export activity.

Despite the uniformity in coefficient directionality, there is substantial variation in the magnitude of those effects, as well as their statistical significance. The size-effect of covariates is consistently largest in the Exponential model, followed by the Weibull and then the CPH model. In the CPH, the only exceptions in this regard are the number of employees and labour productivity, whose coefficients substantially exceed either alternative model, and which incidentally are the only significant covariates in the CPH. In comparison, all covariates are highly significant (at $p < 0.01$, with the exception of lagged export volume, which is significant at $p < 0.05$ in the Weibull and insignificant in the Exponential model) in both the Weibull and Exponential model. Further, the Weibull and Exponential model exhibit relatively similar effect-sizes, in particular in regards to capital-intensity, formation year, export and domestic supply volumes, although the exponential model produces larger effect sizes for productivity.

The very different behavior of covariates in the CPH model may proximately indicate that their estimated effects are to be accepted cautiously across models. While that is certainly the case, it should also be emphasized that the inclusion of time-varying covariates makes it more probable that the proportionality assumption underlying the CPH is violated, or more precisely speaking, that such a violation is detected. Hence, the Schoenfeld Residual Test (SRT) is employed on the CPH model. Specifically, the SRT tests for linearity in the association between covariates and the hazard rate at different points in time (Park & Hendry, 2015). If that relationship diverges sufficiently between observed periods, the proportional hazards assumption should be deemed violated and covariate estimators will be biased and

**Table 5.1** Export Initiation Timing: Discrete survival estimations on *naïve* sample of French fabricated metal manufacturing firms with time-varying covariates, 1995-2019

| | Cox Prop. Hazards | Weibull | Exponential |
|---|---|---|---|
| *Firm-Level* | | | |
| log labour productivity | 0.359*** | 0.166*** | 0.281*** |
| | (0.073) | (0.047) | (0.073) |
| log capital intensity | -0.009 | -0.140*** | -0.180*** |
| | (0.076) | (0.041) | (0.064) |
| log no. employees | 0.638*** | 0.197*** | 0.362*** |
| | (0.092) | (0.056) | (0.081) |
| log investment | 0.039 | 0.149*** | 0.196*** |
| | (0.066) | (0.040) | (0.059) |
| formation year | 0.034 | 0.106*** | 0.121*** |
| | (0.042) | (0.020) | (0.032) |
| *Industry-Level* | | | |
| GLI | 2.471 | 5.684*** | 6.650*** |
| | (2.100) | (1.004) | (1.566) |
| log export supply volume | -0.005 | -0.412** | -0.478 |
| *(1st lag)* | (0.336) | (0.190) | (0.304) |
| log domestic supply volume | -1.286 | -2.286*** | -2.762*** |
| *(1st lag)* | (1.123) | (0.609) | (0.956) |
| *Ancillary Parameters* | | | |
| log(scale) | | 194.545*** | 221.378*** |
| | | (37.800) | (59.342) |
| log(shape) | | 0.545*** | |
| | | (0.076) | |
| *Summary Statistics:* | | | |
| Max. log likelihood | -2052.668 | -921.95 | -937.81 |
| LR test statistic | 228.9*** | 262*** | 232*** |
| Akaike Information Criterion | | 1863.90 | 1893.62 |
| No. of events | 335 | 335 | 335 |
| No. of observations | 2862 | 2862 | 2862 |

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1, GLI: adjusted Grubel-Lloyd Index

Source: own estimation on ORBIS-data (BvD, n.d.)

frequently appear insignificant (Park & Hendry, 2015; Clark et al., 2003b). Indeed, the null hypothesis – no violation of the proportional-hazards assumption – is rejected (at $p < 0.05$), which may explain the divergent pattern observed in the CPH.

The comparative adequacy (goodness-of-fit) of all three models is tested formally in two ways, by means of Likelihood Ratio Test (LRT) and Akaike Information Criterion (AIC). The LRT is obtained through comparison of the log-likelihood function, which measures the probability of the estimated distribution of export-initiation times under censoring, given the observed export-initiation times (Singer & Willett, 1993). Specifically, the log-likelihood function is estimated with and without covariates for each model. The LRT can then be employed to test whether the inclusion of covariates yields a substantial improvement in the probability of observing the estimated export-initiation distribution, with higher values suggesting better fit over the covariate-less model (Clark et al. 2003b). Although not formally analogous, the LRT can thus be thought of as similar to the Coefficient of Determination in linear regression models. As shown in Table 5.1, the inclusion of covariates employed significantly ($p < 0.01$) improves goodness-of-fit across all three models, most significantly in the Weibull model.

Although by LRT, the Weibull model fares better compared to the Exponential model, it should be noted that the LRT does not account for the extent to which model-fit is driven by the assumptions imposed when deploying either model. To account for this, the AIC is estimated as an alternative measure. The AIC estimates a score value based on models' log-likelihood function while penalizing for model complexity, with lower values indicating higher adequacy when comparing models (Acquah, 2010, Clark et al. 2003b). While this test can only be employed on parametric models (Clark et al. 2003b), this is nonetheless informative. Discriminating for complexity in particular means that a model's log-likelihood is penalized against the number of covariates employed and the number of distributional parameters generated. The shape parameter of the Exponential models' hazard rate is $\gamma = 1$ at all points in time, as opposed to the Weibull model in which the scale parameter can vary freely. Since otherwise both models are identically specified, we thus obtain an explicit measure of whether the flexibility of the Weibull model – obtained at the cost of substantially more parameterization – yields comparatively more, or less appropriate estimation. As shown in Table 5.1, the Weibull model yields a (albeit marginally) smaller AIC estimate, suggesting that even under discrimination against the number of parameters, the Weibull model performs comparatively better.

Finally, the estimation results obtained under strict right-censoring – i.e. the deliberate removal of firms with inconsistently observed export status – are nearly identical to the ones discussed thus far (see appendix A.2). As pointed out before, this was to be expected, but nonetheless lends support to the findings' robustness, since the weaker censoring conditions yield a larger number of observations points for each firm that is right-censored later than would be the case under strict right-censoring.

## 5.2 Discussion

The consistency and significance of results across the Weibull and Exponential model is encouraging in regards to the findings' validity. Indeed, the initial set of hypotheses – most important amongst them the hypothesized relationship between firms' productivity and the speed with which they initiate exports – appear confirmed. Given the significant violation of the proportional-hazards assumption, the divergent results obtained from the CPH model are perhaps less cause for concern than would otherwise be the case. Although only implicitly, the CPH results do however offer an interesting perspective. As was noted during hypothesis development, it may be the case that recently formed firms cannot, and thus do not explicitly base their choice to export on their productivity (Bürgel et al., 2004, p. 96; Ericson & Pakes, 1995). Thus, the violation of the proportional hazards assumption may indicate that (specifically) productivity affects different firms' propensity to initiate exports differently across time. For example, it may be the case that as firms age, they form a more explicit understanding of their productivity, such that – if the ways in which productivity enters into the decision are not substitutive – productivity becomes a more important or at least more explicitly considered determinant of whether firms export the longer they have existed.

Although the existing empirical literature against which this papers' findings are at all comparable is rather thin, several similarities can be observed. Ilmakunnas & Nurmi (2010) in particular obtain a positive effect of labour productivity on the speed with which firms initiate exports as well, and both Ilmakunnas & Nurmi's (2010) and Bürgel et al.'s (2004. pp. 148-51) observe the same relationship with regards to number of employees and firms' formation-time found here. Unlike this papers' findings however, Ilmakunnas & Nurmi (2010) observe that higher capital-intensity is similarly conducive to earlier export-initiation[1]. Importantly, this may be attributable to the nature and context of their inquiry. Amongst other reasons, it is probable that their sample is more representative of small(er) firms than the one employed here[2]. Additionally, it is important to note that the preceding literature frequently controlled for R&D investment, and foreign-ownership or management with previous international experience (Bürgel et al., 2004, pp. 148-51; Ilmakunnas & Nurmi, 2010; Powell, 2014; Zhao & Hsu, 2007). Neither of these characteristics were observable for more than three percent of the sample and were thus not considered as covariates.

With regards to industry-level variables employed in this paper, there unfortunately do not appear to be directly comparable findings. In large part this is perhaps attributable to the fact that given the available data, these controls were not obtainable directly from the firm-population sampled. Nonetheless, one particularly interesting conclusion emerges. Specifically, it appears that the intensity of intra-industry trade (as measured by the lagged GLI) increases the speed with which firms initiate exports. It thus seems possible that increased intra-industry trade reflects positive spill-over effects made possible by e.g. a higher degree of economic integration, rather than directly the nature of competition in the export

[1] Although it should be noted that Bürgel et al. (2004. pp. 148-51) do not differentiate the mode in which firms enter foreign markets.

[2] It is further not obvious how they define firms' capital stock, which may substantially contribute to the differing results.

market (Ilmakunnas & Nurmi, 2010).

Perhaps most important however, is to emphasize that – in kind with prior research on firms' formation-to-export time-span – estimation was undertaken *naïvely*, that is, under the assumption that firms' market-exit does not constitute a competing event. As discussed previously, this is by no means an unproblematic assumption, and made only given the constraints of available data. Similarly, duration models fundamentally operate under the assumption that all units of observation eventually experience the event-of-interest (Amico & Van Keilegom, 2018; Legrand, 2021, p. 153). While the theory that informs this paper implies that this assumption is satisfied, it does so by design. As pointed out before however, accounting for this possibility econometrically is unlikely to yield informative results if firms' market-exit cannot be accounted for. The results obtained in this paper are thus likely to be biased, and conditional on the frequency with which firms' exit the market prior to initiating exports, that bias may be severe. Since however neither of these concerns have been addressed in previous research on the formation-to-export time-span of firms, it is impossible to make precise judgments about the extent to which they are indeed problematic.

# 6. Conclusion

This paper investigated empirically how the speed with which firms' initiate exports for the first time is affected by their productivity. Employed were in particular three discrete-time duration models: The Cox Proportional Hazards, Weibull, and Exponential model, with results uniformly suggesting that productivity significantly shortens the formation-to-export time-span. Controlling for industry-characteristics, firms' size (labour employed), investment into physical capital, and later market entry are similarly found to have a shortening effect. Conversely, capital-intensity is found to have a lengthening effect, suggesting that firms which rely relatively more on capital than labour enter export markets more slowly.

An interesting perspective emerges in particular from the Cox Proportional Hazards model. Productivity may become increasingly important in firms' choice to initiate exports the longer they have operated in the domestic market. This finding is consistent with previous research into newly formed firms which suggests that young firms, for lack of experience, have not yet formed an explicit understanding of their productive capacity, instead judging their capabilities through more tangible factors.

Further, it appears that the sparse empirical literature on this matter is yet to investigate the extent to which the firms' market-exit constitutes a competing event in relation to firms' export-initiation. Since this has so far not been accounted for methodologically, previous findings, like those obtained in this paper, are likely to suffer from bias. Further, since trade-theoretical research has historically focused primarily on which, rather than when firms initiate exports, it has thus far usually been assumed that most firms never trade. However, in accounting for firms' market-exit, future research may find that this is an incomplete assessment. Consequently, two important considerations for future research emerge: The deployment of duration models to examine firm's formation-to-export time-span likely requires competing-risk, and cure components.

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# Appendices

## A.1 Auxilliary Estimations

**Table A.1** Correlation Between Observed and Internally Imputed Value-Added, 1995-2019

| year | observations | correlation coefficient |
|---|---|---|
| 1995 | 3 | 0.9999934*** |
| 1996 | 15 | 0.9999637*** |
| 1997 | 25 | 0.9999736*** |
| 1998 | 47 | 0.9990236*** |
| 1999 | 72 | 0.9981657*** |
| 2000 | 118 | 0.9917473*** |
| 2001 | 163 | 0.9844136*** |
| 2002 | 171 | 0.9867371*** |
| 2003 | 148 | 0.9309737*** |
| 2004 | 171 | 0.9906179*** |
| 2005 | 198 | 0.9976993*** |
| 2006 | 231 | 0.9803828*** |
| 2007 | 284 | 0.9793880*** |
| 2008 | 339 | 0.9867130*** |
| 2009 | 369 | 0.9888746*** |
| 2010 | 394 | 0.9880912*** |
| 2011 | 426 | 0.8731121*** |
| 2012 | 467 | 0.9924708*** |
| 2013 | 463 | 0.9858501*** |
| 2014 | 319 | 0.9946493*** |
| 2015 | 285 | 0.9846573*** |
| 2016 | 250 | 0.9976423*** |
| 2017 | 233 | 0.9977465*** |
| 2018 | 227 | 0.9956302*** |
| 2019 | 214 | 0.9977842*** |

*** p<0.01, ** p<0.05, * p<0.1

Source: own calculation on ORBIS-data (BvD, n.d.)

**Table A.2** Export Initiation Timing: Discrete survival estimations on *naïve* sample of French fabricated metal manufacturing firms with time-varying covariates, 1995-2019, strict censoring conditions

| | **Cox Prop. Hazards** | **Weibull** | **Exponential** |
|---|---|---|---|
| *Firm-Level* | | | |
| log labour productivity | 0.358*** | 0.166*** | 0.280*** |
| | (0.073) | (0.047) | (0.073) |
| log capital intensity | -0.006 | -0.139*** | -0.179*** |
| | (0.076) | (0.041) | (0.064) |
| log no. employees | 0.640*** | 0.197*** | 0.361*** |
| | (0.092) | (0.057) | (0.081) |
| log investment | 0.036 | 0.147*** | 0.194*** |
| | (0.066) | (0.040) | (0.059) |
| formation year | 0.034 | 0.109*** | 0.126*** |
| | (0.042) | (0.021) | (0.032) |
| *Industry-Level* | | | |
| GLI | 2.509 | 5.832*** | 6.856*** |
| | (2.107) | (1.013) | (1.580) |
| log export supply volume | -0.006 | -0.418** | -0.490 |
| *(1st lag)* | (0.337) | (0.190) | (0.305) |
| log domestic supply volume | -1.288 | -2.324*** | -2.823*** |
| *(1st lag)* | (1.123) | (0.611) | (0.959) |
| *Ancillary Parameters* | | | |
| log(scale) | | 199.833*** | 229.594*** |
| | | (38.120) | (59.877) |
| log(shape) | | 0.545*** | |
| | | (0.077) | |
| *Summary Statistics:* | | | |
| Max. log likelihood | -2049.667 | -919.45 | -935.1 |
| LR test statistic | 227.3*** | 262*** | 231*** |
| Akaike Information Criterion | | 1858.90 | 1888.19 |
| No of events | 334 | 334 | 334 |
| No of observations | 2856 | 2856 | 2856 |

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1, GLI: adjusted Grubel-Lloyd Index

Source: own estimation on ORBIS-data (BvD, n.d.)

## A.2 Statement on the Use of AI

In the process of writing this thesis, AI has been employed for three purposes: (1) The identification and troubleshooting of problem-causes in erroneous code in R, in which the empirical portion of this thesis was performed; (2) Streamlining of inefficient or otherwise problematic code in R; (3) troubleshooting of LATEX code for formatting of visuals.