Learning versus Sunk Costs Explanations of Export Persistence

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Abstract

This paper explores the role of sunk costs versus learning in explaining persistence in exporting. Multiple studies attributed such persistence to sunk market-entry costs. This paper shows that similar patterns of exporting are also consistent with a learning mechanism and finds a strong empirical support for such a mechanism in the context of Colombian plant-level data. Second, the paper empirically discriminates between the two competing theories, and finds that once learning is controlled for, the role of sunk costs in generating export persistence is at most forty percent of what is currently estimated in the literature. Finally, while in differentiated-products industries export persistence arises primarily due to learning, in the homogeneous-products industries such persistence arises primarily due to the sunk-cost mechanism.

Keywords: Learning, sunk costs, export participation, state dependence

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1. Introduction

One remarkable feature of export behavior is its surprising persistence. Despite adverse productivity shocks or exchange rate fluctuations, over eighty percent of exporters continue to export in the following period. While multiple studies attributed such persistence to the presence of sunk market-entry

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costs, a new literature on learning suggests that it might be the accumulation of market experience which increases firms' profitability over time and allows them to continue exporting. As shown in Arkolakis, Papageorgiou, and Timoshenko (2013), if learning is present, aggregate economic welfare can be improved by subsidizing young firms. This implication does not hold if there are no learning mechanisms governing firms' behavior. Therefore, in order to develop and implement welfare enhancing (trade) policies, one must clearly establish the sources of export persistence. This paper investigates the role of learning in predicting a firm's export choice and disentangles the roles of sunk costs and learning to account for export persistence.

In the model, learning takes the form of the age-dependence hypothesis. I assume that conditional on productivity, a firm's sales increase with export experience. Thus, older or more experienced exporters are more profitable in foreign markets compared to younger or less experienced exporters, all else equal. Given this assumption, the model generates persistence in exporting in the following way: profitability in a market rises with the length of export experience. If a firm exits the market, the returns to export experience will depreciate. Upon subsequent re-entry, this firm will start with a lower stock of experience, and thus lower level of sales. This value associated with the duration of export experience induces firms to continue exporting. Hence, the model naturally yields persistence in exporting.

The theoretical framework implies that the empirical identification of learning relies on the predictive power of export experience or export history in explaining export sales and export choice. Using Colombian plant-level data for the period between 1979 and 1989, I estimate an export sales equation implied by the model and find strong evidence for learning. Export experience or export age is significant in predicting export sales volume. I further use the model to derive an empirical export-participation equation and also find a strong support for the learning mechanism: each additional year of exporting (up to three years) increases the current probability of exporting.

The model further provides an important guidance for the empirical identification of sunk costs versus learning in accounting for persistence in exporting. In a nutshell, persistence in exporting is inferred from regressing current export choice on the export choice in the previous period (one-year lagged exporting), controlling for observed and unobserved firm-level characteristics. The statistically significant coefficient on one-year lagged exporting is

evidence for persistence in exporting and is usually attributed to sunk costs.¹ I will refer to this coefficient as the state-dependence parameter.

When sunk costs are combined with the learning mechanism described above, the model clearly shows that this state-dependence parameter absorbs the effect of both sunk costs and learning. Thus, previous findings of statistically significant state dependence can be interpreted only as evidence for persistence in exporting (structural state dependence in exporting, to be precise), and not necessarily as evidence favoring the sunk-cost mechanism. As shown in this paper, the identification of sunk costs versus learning must rely on the functional form assumption of how learning affects exporting. For the benchmark specification, I use a logarithmic parameterization of the age effect to decompose the state-dependence parameter into the sunk-cost and the age components. The decomposition of the state-dependence parameter results in the sunk-cost component accounting for a half, and the age component for the other half, of the effect of one-year lagged exporting. Furthermore, in comparison to the standard estimates, the overall effect of sunk costs in accounting for export persistence declines by 60 percent.

The paper further establishes that the relative magnitudes of the two source of export persistence vary across industries. Industries are divided into two broad types according to the Rauch (1999) classification. Homogeneous industries are comprised of products which are traded on an organized exchange or which possess a reference price. Differentiated industries are comprised of all other products. One might expect stronger learning effects among differentiated products. In such an environment, consumers gradually learn their tastes for individual varieties. They can also easily switch to alternative varieties if the preferred variety is not offered for a period of time. Thus, firms are more likely to value market presence and continue to export. I find that overall there is slightly stronger state dependence in exporting among homogeneous industries which primarily arises due to sunk costs. In contrast, only a quarter of the state dependence in exporting within differentiated industries arises from sunk cost, with the rest being attributed to learning.

The finding that export persistence is primarily driven by learning rather

¹Roberts and Tybout (1997) were the first to develop the method and show the relation of the state-dependence parameter to sunk costs. Roberts and Tybout (1997), followed by Bernard and Jensen (2004), Bernard and Wagner (2001), and Campa (2004) also find the state-dependence parameter to be statistically significant.

than sunk costs is crucial in the context of literature which explores the role of various economic policies in enhancing aggregate welfare. On the theoretical front, Arkolakis, Papageorgiou, and Timoshenko (2013) explore welfare implications of a learning model which is similar to the one considered in this paper. The authors find that aggregate welfare can be improved by subsidizing young firms. Subsidies to young firms allow them to survive for a number of extra periods and learn with greater precision their profitability in a market. In this way, subsidies prevent early exit of potentially profitable firms. The finding that continuous export participation is primarily driven by learning as opposed to sunk costs offers novel grounds for thinking about types of policy instruments which can enhance growth and survival of exporters, and ultimately aggregate welfare. This dimension of research is outside the scope of this paper, but the paper provides substantial evidence to motivate subsequent studies to investigate the role of information mechanism in stimulating export behavior.

A number of other studies have empirically documented the role of information in firms' decisions. Based on individual interviews with exporters, Artopoulos, Friel, and Hallak (2013) find that the greatest obstacle to exporting is the lack of information about foreign distributors, uncertainty about demand for products, and outdated business practices. The pioneering exporters are those which possess greater knowledge and information about foreign markets. Mion and Opromolla (2011) find that the higher is the share of managers with previous export experience, the more likely a firm is to start exporting. My study contributes to the literature by finding that the duration of exporting increases the subsequent probability of exporting, and thus provides an implicit evidence for in-the-market learning. Together, the literatures suggest that to enhance the growth and survival of exporters, various instruments or policies should enhance information transmission about foreign markets.

The findings in this paper contribute to the literature on the role of learning versus sunk costs in explaining various dimensions of firm behavior. For example, using a similar age-dependent sales assumption, Ruhl and Willis (2008) show that, in contrast to the sunk-cost model, such learning model can replicate the behavior of export-sales ratio and the conditional survival probability of new exporters. My paper contributes to the discussion by showing that similar assumption is helpful in identifying the sources of persistence in exporting. Although seeking to rationalize different aspects of firm behavior, both papers come to the conclusion that the imputed value

of sunk costs must be much smaller if learning is taken into account. This paper further finds strong support for learning.

This paper is related to a broader literature on learning and sunk costs. One dimension of learning is market experimentation. Albornoz, Calvo-Pardo, Corcos, and Ornelas (2012) find that market experimentation can rationalize gradual entry of exporters into new markets and exporters' slow sales growth in the initial years. Eaton, Eslava, Krizan, Kugler, and Tybout (2012) observe that sales of a large proportion of exporters are very small compared to the high magnitude of the sunk costs estimated by Das, Roberts, and Tybout (2007). Alessandria and Choi (2007) find a negligible role of sunk costs in aggregate business cycle fluctuations of firm entry and exit.

The methodology to identify learning in this paper is related to the work of De Loecker (2013). Instead of affecting export sales, the author assumes that export experience directly affects the productivity of a firm. De Loecker (2013) makes a strong argument that if such direct dependence of productivity on export experience is omitted from empirical models, the results are biased toward rejecting the learning hypothesis. My paper shows that in the context of sunk costs versus learning debate, omitting the learning mechanism leads to the evidence being biased in favor of the sunk-cost theory.

The paper extends the work on estimating an export-participation equation derived from a sunk-cost model. Using data for various countries, Roberts and Tybout (1997), Bernard and Jensen (2004), Bernard and Wagner (2001), and Campa (2004) find that exporting in the previous period predicts current export choice and attribute this effect to sunk costs. This paper derives a similar export participation equation, but from a model that incorporates both sunk costs and learning. The resulting empirical export-participation equation differs from the traditional one by incorporating the full continuous export history of a firm as explanatory variables, rather than only incorporating the one-year lagged export status.

The modeling of learning as age-dependent sales finds its support in micro-founded work of Arkolakis, Papageorgiou, and Timoshenko (2013) and its extension by Timoshenko (2014). The learning model in these papers assumes that firms are uncertain about the appeal for their products and must learn about it in the presence of transient preference shocks. As firms continue to export, they observe subsequent demand signals, and gradually learn about their appeal. Such model yields age-dependence of sales, growth, and the product switching behavior of firms. This paper adopts a reduced-form

representation of such a mechanism by directly assuming age-dependence of sales and exploring the implications for this assumption for persistence in exporting.

The paper will proceed as follows. Section 2 describes the theoretical framework, explains the age-dependence assumption and discusses the implications of the model for the decomposition of the state-dependence parameter. Section 3 describes the estimation of the export sales equation and develops an empirical model of export participation. Section 4 describes the data and empirical patterns. Section 5 presents estimation results. Section 6 concludes.

2. Theoretical Framework

Consider firm i at time t with productivity denoted by $z_{i,t}$ and export experience denoted by $A_{i,t}$. Let $A_{i,t}$ measure the duration of the firm's most recent export spell, i.e. the number of years the firm continuously exported immediately before arriving to period t . For example, $A_{i,t} = 0$ if a firm did not export in period $t - 1$ (irrespective of the firm's export history prior to period $t - 1$). $A_{i,t} = n$ implies that a firm exported in all periods between $t - 1$ and $t - n$. Let productivity $z_{i,t}$ follow an AR1 process of the form $z_{i,t} = \phi z_{i,t-1} + \epsilon_{i,t}^z$.

Given its productivity and prior export experience, every period t the firm decides whether to export or not. Exporting yields per-period sales which are given by

$$S(z_{i,t}, A_{i,t}) = g(A_{i,t}) E_t P_t^{\sigma-1} \left(\frac{\sigma}{\sigma-1} \frac{\tau w_t}{e^{z_{i,t}}} \right)^{1-\sigma}. \quad (1)$$

Except for the new component $g(A_{i,t})$, this is a standard sales function which arises from models of monopolistic competition with constant elasticity of substitution preferences such as Melitz (2003). In equation (1), E_t is the aggregate expenditure level in an export market, P_t is the aggregate price index, w_t is the wage rate, τ is the "iceberg" transportation cost, and σ is the elasticity of substitution.

If the firm chooses to export, it receives per-period profit $\pi(z_{i,t}, A_{i,t}) = \frac{S(z_{i,t}, A_{i,t})}{\sigma}$. If this firm did not export in the previous period, it also incurs a sunk market-entry cost f_e . If the firm chooses not to export, it receives zero per-period payoff.

Equation (1) makes a crucial assumption: a firm's sales and, therefore, profitability in an export market directly depend on the firms' export experience $A_{i,t}$. I assume that, all else equal, more experienced (or older) exporters are more profitable in foreign markets compared to less experienced (or younger) exporters. Specifically, $g(A_{i,t})$ is increasing in $A_{i,t}$. I will refer to this assumption as *the age-dependence assumption*. It is crucial in identifying the sources of persistence in exporting and deserves a thorough discussion below.

2.1. Conditional Age Dependence

Empirical literature on firm dynamics finds positive experience effects on firms' performance beyond productivity and selection effects. In the context of U.S. manufacturing plants, Foster, Haltiwanger, and Syverson (2012) empirically investigate the sources of sales-size differences between young and old plants. Controlling for plants' productivity, the authors find that young plants have systematically lower sales than older plants due to the lower levels of a demand measure. It is exactly the low initial levels of demand, and not productivity, which yield new entrants being small. The authors find that as firms age and accumulate market experience, their demand measures also rise yielding higher sales among older firms. In the context of the assumption made above, $A_{i,t}$ exactly captures this effect of experience, demand, or learning on firms' profitability.

While the empirical literature is able to estimate the demand effect on profitability of firms over their lifespan and vaguely attribute such effect to learning, the theoretical literature on firm dynamics provides micro-foundations for such learning effects and the age-dependence assumption made above. For example, in Arkolakis (2010) firms need to pay market penetration costs to reach consumers. While Arkolakis (2010) set-up is static, it can be hypothesized that as firms continue to sell and invest into reaching consumers, their customer base gradually grows. Such growth yields corresponding increase in sales and profits over time which occurs solely due to the accumulation of experience or market presence, and is captured by $A_{i,t}$ in the specification above. Arkolakis, Papageorgiou, and Timoshenko (2013) and Timoshenko (2014) directly incorporate learning by firms about their uncertain demand in foreign markets into a dynamic framework of firms' behavior. The authors show that demand learning leads to the, conditional on size, age dependence of growth rates, survival probabilities, and product switching behavior of firms.

In sum, both the theoretical and empirical literature point to the fact that conditional on productivity, firms' sales increase with experience, be it demand, learning, or simply market presence. To capture such a mechanism, this paper assumes that sales directly increase as export experience rises. I will hence refer to this assumption as the age-dependence assumption or the learning assumption. As will be shown below, the presence of such a mechanism crucially affects the identification of the sources of persistence in exporting. The persistence in exporting previously attributed by the literature to sunk costs can instead arise due to the accumulation of market experience, or what is generally referred to as learning.

2.2. Export Participation Decision

Denote by $Y_{i,t}$ a firm's export decision, such that $Y_{i,t} = 1$ if a firm exports in period t and zero otherwise. The firm chooses its export status to maximize the presented discounted value of profits. This problem can be described by the following Bellman Equation

$$\begin{aligned} V(z_{i,t}, A_{i,t}, Y_{i,t-1}) = \max_{Y_{i,t} \in \{1,0\}} \{ & (\pi(z_{i,t}, A_{i,t}) - f_e(1 - Y_{i,t-1}) + \\ & + \delta E_{z_{i,t+1}} V(z_{i,t+1}, A_{i,t+1}, Y_{i,t}), \delta E_{z_{i,t+1}} V(z_{i,t+1}, 0, Y_{i,t})) \}, \end{aligned} \quad (2)$$

where δ is the discount factor.

In the absence of the age dependence of profits, problem (2) is a well-studied export participation problem of a firm in the presence of uncertainty and sunk costs.² The policy function is characterized by two productivity thresholds: the entry threshold, z_H , and the exit threshold, z_L (where $z_L < z_H$), such that

$$Y_{i,t} = \begin{cases} 1, & \text{if } z_{i,t} \geq z_H - (z_H - z_L)Y_{i,t-1} \\ 0, & \text{otherwise} \end{cases}. \quad (3)$$

Equation (3) implies that a firm exports in period t if its productivity $z_{i,t}$ surpasses a productivity threshold. That threshold depends on the firm's

²The entry decision under uncertainty is initially formulated and studied in Dixit (1989a). Dixit (1989b) analyzes the problem in the context of exchange rate uncertainty. Subsequently, Roberts and Tybout (1997) study export hysteresis in the presence of sunk costs. Impullitti, Irarrazabal, and Opromolla (2013) theoretically study the properties of a sunk-cost model of trade in continuous time.

previous export status. If the firm previously exported ($Y_{i,t-1} = 1$), $z_{i,t}$ has to be higher than z_L . If the firm did not export, current productivity $z_{i,t}$ needs to surpass a higher productivity threshold z_H . Thus, the sunk costs introduce a wedge, a hysteresis band ($z_H - z_L$), between the entry and exit thresholds. Hence, the probability of exporting depends on a firm's export status in the previous period: firms which exported in the previous period are more likely to continue exporting compared to identical domestic firms without previous export experience.

The higher the magnitude of the fixed costs, the larger the hysteresis band, the stronger the persistence in exporting. If fixed costs are zero, $z_L = z_H$ and the probability of exporting is independent of the previous export history. It is exactly this implication which is used to empirically test for the presences of sunk costs as in Roberts and Tybout (1997), to structurally estimate the magnitude of sunk costs as in Das, Roberts, and Tybout (2007), and to attribute persistence in exporting to the sunk-cost hypothesis.³ The age dependence of profits on export experience, or market learning from a broader perspective, alters these results and interpretations.

Proposition 1 below describes properties of the export participation thresholds when profits depend on export experience, conditional on productivity.

Proposition 1. *Properties of the export participation thresholds*

- a) $z_L(A_{i,t})$ is decreasing in $A_{i,t}$;
- b) If $f_e = 0$, $z_H = z_L(0)$;
- c) If $f_e > 0$, $z_H > z_L(0)$.

The proof of Proposition 1 is included in Appendix A. Notice that the hysteresis band, defined as $[z_H - z_L(A_{i,t})]$, now depends on export experience. Since $z_L(A_{i,t})$ declines in $A_{i,t}$, the hysteresis band is wider for more experienced exporters. Hence, all else equal, they will be more likely to continue to export compared to less experienced exporters. Thus, if profits depend on age, or broadly speaking there is learning, continuous export history matters for predicting current export choice. This implication will be examined in Section 3 to empirically test for learning.

The dependence of the hysteresis band on export experience introduces a novel interpretation to the sources of persistence in exporting. The policy

³Further studies that rely on this method include Bernard and Jensen (2004), Bernard and Wagner (2001), Campa (2004).

function can now be written as

$$Y_{i,t} = \begin{cases} 1, & \text{if } z_{i,t} \geq z_H - ([z_H - z_L(0)] + [z_L(0) - z_L(A_{i,t})]) Y_{i,t-1} \\ 0, & \text{otherwise} \end{cases}, \quad (4)$$

where $z_L(0)$ is added to and subtracted from the coefficient on $Y_{i,t-1}$ for the clarity of the argument to follow.

Notice that persistence, or state dependence, in exporting can arise even if the sunk costs are zero. By part b) of Proposition 1, if $f_e = 0$, $z_H = z_L(0)$ and the coefficient on $Y_{i,t-1}$ becomes $z_L(0) - z_L(A_{i,t})$. Intuitively, in the absence of fixed costs, but with the presence of learning, a firm is more likely to continue exporting since obtained through exporting information increases per period profits. Such experience effect gradually depreciates once the firm stops exporting, and upon subsequent re-entry, the firm will start off with a lower level of profits.⁴ The firms will then need to wait longer for a higher productivity shock to become an exporter.

Equation (4) demonstrates that the dependence of an export choice today on an export choice in the previous period is merely an indication of a state dependence in exporting, but not necessarily of the sources of such state dependence. In the next section, policy function (4) is used to derive an empirical export-participation equation which will be estimated to empirically discriminate between the sunk costs and learning explanations for persistence in exporting.

3. Empirical Approach

This section develops empirical models that will be used to test the age-dependence assumption and to investigate the sources of state dependence in exporting.

3.1. Age Dependence of Sales

The interest lies in estimating the effect of export experience on export sales. In the context of equation (1), this translates into understanding the behavior of function $g(A_{i,t})$. On the one hand, if there are no returns to export experience, i.e. there is no learning, one would find no dependence of

⁴In the context of the formulation here, export experience fully depreciates immediately upon exit from an export market.

export sales on export age, or that function $g(\cdot)$ is constant with respect to export age. On the other hand, the shape of function $g(\cdot)$ would provide information on whether there are increasing or decreasing returns to experience or learning.

To estimate the returns to experience, I log-linearize equation (1) to obtain

$$\ln(S_{i,j,t}) = \sum_{k=1}^T D_k(A_{i,t} = k) + \alpha_1 \ln(\text{FTP}_{i,j,t-1}) + \alpha_2 X_{i,j,t} + \xi_{j,t} + u_{i,j,t}, \quad (5)$$

where $S_{i,j,t}$ denotes the value of exports of firm i in industry j at time t . Function $g(\cdot)$ is approximated by a set of dummy variables $D_k(A_{i,t} = k)$, each of which equals 1 if at time t firm i was exporting for k consecutive years. If the estimated values of D_k s were not statistically significant, the age-dependence hypothesis would not likely to hold. Positive and statistically significant values of D_k s would serve as a strong support in favor of the age-dependence hypothesis.

The regression in (5) includes firm's total factor productivity, $\text{FTP}_{i,j,t-1}$.⁵ Variables in $X_{i,j,t}$ are firm level controls. Variables $\xi_{j,t}$ are industry-time fixed effects capturing the ratio $E_t(P_t)^{\sigma-1}$. $u_{i,j,t}$ is the error term which is independently, identically, and normally distributed across plants over time. In the context of equation (1), $u_{i,j,t}$ can be interpreted as an unexpected intertemporal demand shock faced by firm i at time t .⁶ Equation (5) is estimated using ordinary least squares method. The firm level controls will include firm fixed effects, an ownership dummy (corporation versus proprietorship and partnership), a location dummy, a firm's age, capital stock, and wage rate. The last three variables are lagged one period and measured in logarithms.

3.2. Empirical Model of Export Participation

To develop an empirical model of export participation, consider equation (4). Denote the coefficient in front of $Y_{i,t-1}$ by β . I will hence refer to β as the state dependence parameter. Notice, that when age equals zero, $\beta =$

⁵A firm's total factor productivity is estimated using Levinsohn and Petrin (2003) estimator based on value added as described in Levinsohn, Petrin, and Poi (2004).

⁶Function $g(A_{i,t})$ can be written as $g(A_{i,t}) = h(A_{i,t})e^{u_{i,j,t}}$, where $h(A_{i,t})$ captures the deterministic component of firms' learning (estimated in equation (5)) and it is subject to transient i.i.d. demand shocks $u_{i,j,t}$.

$z_H - z_L(0)$; when age equals one, $\beta = z_H - z_L(1)$, etc. Define $\beta_j = z_H - z_L(j)$ when age equals j . Then, equation (4) can then be written as

$$Y_{i,t} = \begin{cases} 1, & \text{if } \alpha + \sum_{j=0}^{+\infty} \beta_j Y_{i,t-1} I(A_{i,t} = j) + z_{i,t} \geq 0 \\ 0, & \text{otherwise} \end{cases}, \quad (6)$$

where $I(A_{i,t} = j)$ is the indicator function which equals 1 if $A_{i,t} = j$, and 0 otherwise. Appendix B shows that equation (6) can be manipulated to yield the first estimating equation

$$Y_{i,t} = \begin{cases} 1, & \text{if } \alpha + \beta_1 Y_{i,t-1} + \sum_{j=2}^{+\infty} \lambda_j \hat{Y}_{i,t-j} + \epsilon_{i,t} \geq 0 \\ 0, & \text{otherwise} \end{cases}, \quad (7)$$

where $\epsilon_{i,t}$ is the error term and its structure will be described in detail in Section 3.3 below. $\hat{Y}_{i,t-j} = \prod_{k=1}^j Y_{i,t-k}$. Variable $\hat{Y}_{i,t-j} = 1$ if a firm was an exporter for at least the past j consecutive years. Coefficient $\lambda_j = z_L(j - 1) - z_L(j)$.

Equation (7) separates the marginal effect of j 's years of exporting from the state-dependence parameter, and can be used to test the age-dependence hypothesis. If there is no learning, the exit threshold is independent of age, and thus each λ_j equals zero, otherwise $\lambda_j > 0$. I will henceforth refer to λ_j s as the age effects. Thus, in estimating equation (7), the finding that the coefficients λ_j are statistically significant will serve as supporting evidence for the age-dependence hypothesis.⁷

Even after controlling for learning by including the age terms $\hat{Y}_{i,t-j}$ in equation (7), the state-dependence parameter, now β_1 , cannot separately identify the sunk-cost effect from the marginal effect of the first year. Notice that β_1 , defined as $z_H - z_L(1)$, can be written as $\beta_{sc} + \lambda_1$, where $\beta_{sc} = z_H - z_L(0)$ and $\lambda_1 = z_L(0) - z_L(1)$. If there are no sunk entry costs, Proposition 1 states that $z_H = z_L(0)$ and, thus, $\beta_{sc} = 0$, otherwise $\beta_{sc} > 0$. I will thus refer to β_{sc} as the sunk-cost component of the state-dependence parameter, and λ_1 as the learning effect of the first year of exporting.

⁷Heckman (1981a) shows that a model with lag structure as in (7) is consistent with a behavioral process that emphasizes spell-specific experience accumulation. Here I derive this specification from a fundamental model of export participation where spell-specific experience is taken to be the firm's export age.

To separate the two components of the state dependence parameter β_1 , I will proceed by assuming the logarithmic parameterization of the age effect. Note that (4) can be written as

$$Y_{i,t} = \begin{cases} 1, & \text{if } \alpha + \beta_{sc}Y_{i,t-1} + (z_L(0) - z_L(A_{i,t}))Y_{i,t-1} + \epsilon_{i,t} \geq 0 \\ 0, & \text{otherwise} \end{cases}. \quad (8)$$

The effect of age on exporting is given by $z_L(0) - z_L(A_{i,t})$ which, I am going to assume, takes the following functional form: $\beta_a \ln(A_{i,t} + 1)$.⁸ The second estimating equation becomes

$$Y_{i,t} = \begin{cases} 1, & \text{if } \alpha + \beta_{sc}Y_{i,t-1} + \beta_a \ln(A_{i,t} + 1) + \epsilon_{i,t} \geq 0 \\ 0, & \text{otherwise} \end{cases}. \quad (9)$$

It is useful to compare the marginal effect of the j 's year of exporting in equations (7) and (9). In equation (7) it is given by λ_j , while in (9) it is given by $\beta_a \ln\left(\frac{j+1}{j}\right)$. This is exactly the implicit functional form restriction on the relation between λ_j s, imposed by the logarithmic functional form, that helps to separate the state dependence effect into the two components. Note that in (7), the effect of one year of exporting is captured by β_1 , while in (9) it is given by $\beta_{sc} + \beta_a \ln(2)$, which is the desired decomposition.

3.3. Econometric Considerations

In identifying structural state-dependence parameters, β_1 , β_{sc} , β_a , and λ_j s, it is crucial to control for various sources of persistence in export participation arising from variation in firm characteristics. Thus, in addition to various lags in exporting, I will include the following set of explanatory variables, $X_{i,t}$, in equations (7) and (9) that will control for observed characteristics: time dummies, a set of industry dummies at the two-digit ISIC level, an ownership dummy (corporation vs. proprietorship and partnership), a location dummy, capital stock, wage rate, productivity, and plant age. Capital stock, wage rate, productivity and plant age lagged one period and measured in logarithms.

It is important to note that, for simplicity, the theoretical model assumes full depreciation of sunk costs and export experience once a firm exits the

⁸Note that in (8), multiplication of the age effect by $Y_{i,t-1}$ is redundant. Whenever $Y_{i,t-1} = 0$, then $A_{i,t} = 0$, and thus $z_L(0) - z_L(A_{i,t}) = 0$.

market. It is possible however that the firm can partially recoup previously paid costs upon subsequent re-entry.⁹ In such case, the firm's problem in equation (2) should include an additional state variable, namely - the duration of a period since the most recent exit; the sunk cost would then be a function of that variable. To account for such possibility in the empirical estimation of the export-participation equation I will include a set of dummy variables, $\tilde{Y}_{i,t-j}$, which control for the depreciation of export experience. $\tilde{Y}_{i,t-j} = 1$ if a firm last exported in year $t - j$.¹⁰

To control for unobserved heterogeneity I assume that the error term $\epsilon_{i,t}$ in equation (9) consists of two components: a plant random effect κ_i and the error term $\eta_{i,t}$.

$$\epsilon_{i,t} = \kappa_i + \eta_{i,t}.$$

Component κ_i captures variation in unobserved characteristics across plants (for example, managerial talent or quality). I assume κ_i is independently, identically, and normally distributed across plants with mean zero, variance σ_κ^2 , and $Cov(\kappa_i, X_{i,t}) = 0$. To allow for possible persistence in the unobserved plant-level shocks over time (for example, persistence in profitability shocks), I assume that the error term is autocorrelated, i.e. $\eta_{i,t} = \rho\eta_{i,t-1} + e_{i,t}$, where $e_{i,t}$ is independently, identically, and normally distributed across plants and time with mean zero and variance one. Similarly to the interpretation in equation (5), $e_{i,t}$ arises from transient demand shocks. Further, $Cov(\kappa_i, \eta_{i,t}) = Cov(\epsilon_{i,t}, X_{i,t}) = 0$.

The unobserved persistence in firm characteristics implies that the initial observations on the lagged export statuses cannot be treated as exogenous. Heckman (1981b) refers to this problem as the “initial-conditions” problem and suggests specifying a reduced-form expression for the initial market-participation decision as a function of the firm's characteristics and of the unobserved firm-level effect. Thus, I assume

$$Y_{i,t'} = \begin{cases} 1, & \text{if } \alpha^0 + \gamma^0 X_{i,t'}^0 + \theta\kappa_i + \eta_{i,t'}^0 \geq 0 \\ 0, & \text{otherwise} \end{cases} \quad (10)$$

⁹Iacovone and Javorcik (2012) for example, emphasize investment in product quality prior to market entry. It is reasonable to assume that once products are upgraded, they will continue to be of high quality regardless of market entry and exit patterns.

¹⁰Similar approach is also taken in Roberts and Tybout (1997).

where t' refers to the time periods of the pre-sample observations. The error term follows $\eta_{i,t'}^0 = \rho^0 \eta_{i,t'-1}^0 + e_{i,t'}^0$, where $e_{i,t'}^0$ is independently, identically, and normally distributed across plants and time with mean zero and variance one, and $Cov(\kappa_i, \eta_{i,t'}^0) = 0$. Parameter θ captures the extent of the endogeneity of the initial conditions. If θ is not statistically different from zero, the initial conditions can be viewed as exogenous. The covariates in $X_{i,t'}^0$ include those in $X_{i,t}$ and three additional explanatory variables (two-period lagged values of capital stock, wage rate, and productivity measured in logarithms) to satisfy the exclusion restriction.

The empirical model in (7) and (10), or (9) and (10), is estimated using a Maximum Simulated Likelihood estimator based on Geweke-Hajivassiliou-Keane algorithm. The details of the estimation procedure are described in Appendix C.

4. Data and Empirical Patterns

The data come from the annual plant-level survey of Colombian manufacturing plants conducted by the census bureau, and cover the period between 1979 and 1989. The export-participation data are available at the plant level for the interval 1981-1989. The data additionally contain annual information on each plant's domestic sales, geographic location, industry (four-digit ISIC), age, ownership structure, capital stock, investment flows, value added, and expenditure on labor and materials.¹¹

To explore variation across industries in the sources of persistence in exporting, I am going to employ Rauch (1999) classification of industries into industries populated with differentiated versus homogeneous products. According to Rauch (1999) classification, a product is described as being homogeneous if it is traded on organized exchange or its price is quoted in a trade publication. Table 1 provides a list of four-digit ISIC industries which can unambiguously be classified as consisting only of differentiated products (Panel A) and as consisting only of homogeneous products (Panel B).

Notice, that not all four-digit ISIC industries are listed in Table 1. This is due to the fact that Rauch (1999) classification of products into differentiated versus homogeneous is available at the four-digit SITC level. This classification is much more disaggregated compared to four-digit ISIC. There are over

¹¹For greater detail regarding the data set see Roberts and Tybout (1997).

Table 1: Classification of Industries into Differentiated versus Homogeneous

Industry Number	Industry Name
<i>Panel A: Differentiated Industries</i>	
3117	Bakery Products
3134	Nonalcoholic Beverages and Soda
3214	Carpets and Rugs
3215	Cordage
322 *	Clothing and Apparel(Excl. Footwear)
3232	Furskins
3233	Other Leather Products (Excl. Clothing and Footwear)
324 *	Footwear, Except Those Principally of Rubber and Plastic
3312	Wood Containers and Small Wicker Products
332 *	Furniture and Accessories, Except Those Principally of Metal
3521	Paint, Vining and Lacquer
355 *	Rubber Products
362 *	Glass Products
3812	Metal Furniture, Excl. Electric Lamps and Accessories
3813	Structural Metal Products
382 *	Machinery (Excl. Electrical Machinery)
3833	Household Electrical Appliances
384 *	Transportation Equipment
3852	Photographic and Ophthalmic Products
3853	Watches
3902	Musical Instruments
3903	Sporting Goods
<i>Panel B: Homogeneous Industries</i>	
3118	Sugar Refining and Sugar Products
3122	Animal Feed
3131	Spirits and Liquor
3133	Malt Products
3411	Pulp Mills
3512	Fertilizers and Pesticides
3692	Concrete, Lime and Plaster

Note: The table lists four-digit ISIC Rev.2 industries which can be unambiguously classified as solely consisting of differentiated products (Panel A) or homogeneous products (Panel B). The classification into differentiated versus homogeneous products is based on Rauch (1999) classification of four-digit SITC products. The concordance between SITC and ISIC is constructed by the OECD.

* All four-digit industries are included.

Table 2: An Example of an Industry Match

ISIC Code	ISIC Name	SITC Code	SITC Name	Product Type
3560	Plastic Products	5831	Polyethylene	homogeneous
		8510	Footweare	differentiated

Note: The classification of SITC products into differentiated versus homogeneous is based on Rauch (1999). The concordance between SITC and ISIC is constructed by the OECD.

two hundred four-digit SITC manufacturing products, compared to under one hundred of four-digit manufacturing ISIC industries. Industries which do not appear in Table 1 are non-exclusively matched into both homogeneous and differentiated products. Table 2 provides one such example.¹²

Table 3 presents the most prominent statistics demonstrating persistence of plants' export decisions: persistence rates for exporters and non-exporters. In panel A of Table 3, each column follows a cohort of plants who were exporters 1981 and continued to export in subsequent years. Thus, out of all exporting plants in 1981, 85 percent continued to export in 1982, and 74 percent continued to export 8 years later, in 1989. In a similar way, panel B of Table 3 follows non-exporting plants. For example, out of all plants which did not export in 1981, 98 percent did not export in the subsequent year, and 92 percent did not export 8 years later, in 1989. The data unambiguously reveal that exporting and non-exporting are highly persistent.

The data presented in Table 3 is consistent with the literature. Similar persistence rates are observed in the context of U.S. manufacturing plants where 79 percent of exporters continue to export 8 years later (Bernard and Jensen, 2004). The data are also consistent with the annual transition rate between export statuses reported in Roberts and Tybout (1997). For example, Roberts and Tybout (1997) show that the average 1982-1989 annual transition rate from exporter to exporter is 87 percent.¹³ In Table 3 the annual transition rates from exporter to exporter statuses (panel A) can be read from the first entry in the first column, which is 85 percent.

¹²The OECD concordance was used to match SITC and ISIC codes. The concordance is available at

<http://www.macalester.edu/research/economics/page/haveman/Trade.Resources/tradeconcordances.html>

¹³Roberts and Tybout (1997) use a sample of nineteen exporting industries.

Table 3: Persistence of Exporting and Non-Exporting, 1981-1989

Year	All	Differentiated	Homogeneous
<i>Panel A: Exporters</i>			
1982	85	78	86
1983	79	65	86
1984	76	61	79
1985	75	63	90
1986	75	68	83
1987	74	65	83
1988	73	65	83
1989	74	66	83
<i>Panel B: Non- Exporters</i>			
1982	98	98	96
1983	97	98	94
1984	96	98	94
1985	94	96	90
1986	93	95	92
1987	94	96	94
1988	93	95	92
1989	92	93	92

Note: Each row of the table calculates the percentage of exporters (non-exports) in the row year who were exporters (non-exporters) in 1981. The table follows a cohort of plants which continuously operated between 1981 and 1989.

Figure 1: **Average Log-Export Sales of Surviving Exporters**

Note: The level of average log-sales across export ages is normalized by the average log-sales of entrants.

Panel A of Table 3 reveals much stronger persistence in exporting among homogeneous-products plants compared to differentiated-products plants. Eighty three percents of homogeneous-products plants continue to export 8 years later compared to only 66 percent of differentiated-products plants. In the context of the theoretical argument in this paper, these patterns suggest that there might be substantial differences in the sources of persistence between homogeneous and differentiated industries. One would expect exporting to be more persistent if sunk costs were higher or if the returns to export experience are stronger. Figure 1 provides some evidence on potential differences in the returns to experience.

Figure 1 depicts the average of the logarithm of export sales of surviving exporters. As can be seen from the figure, the average sales of exporters rise with export age. This observation is consistent with the age-dependence hypothesis. One needs to remember, however, that part of an increase in sales over time can be driven by the selection of the most profitable plants.

Notice, that there is no substantial differences in the returns to export experience between homogeneous- and differentiated-products plants. All

Figure 2: **Conditional Survival Probability of Exporting**

Note: Each point in the figure corresponds to the proportion of firms who reached a given age in the market and continued to export in the following period.

export sales curves in Figure 1 have similar slope and shape as a function of export age. Taken together, patterns in Figure 1 and Table 3 suggest that while returns to learning among homogeneous and differentiated industries might be similar, weaker persistence in exporting among the latter group indicates that sunk costs might be smaller for the differentiated industries. This can be further examined by looking the at survival probability of exporters.

Figure 2 plots conditional survival probability by export age. Each point in the figure corresponds to the proportion of firms who reached an export age given by the x -coordinate and continued to export in the following period. For example, all new exporter-entrants have export age being equal to one. Out of those new entrants, 61 percent will continue to export in the next period. After a year of exporting (when export age equals 2), 76 percent of plants will continue to export in the subsequent period. Overall, the data present a pattern that is consistent with the age-dependent sales hypothesis: the conditional survival rate increases with the firm's age in the market.

There is a stark difference in the behavior of the survival probabilities between differentiated and homogeneous industries. For homogeneous industries, within one year since entry the survival rate jumps from 46 to 90 percent and stays at 100 percent for the majority of subsequent periods. The decline in the survival rate in the fourth and fifth year is due a single outlier: the entry cohort of 1983. If this cohort is excluded, the survival rate is at 100 percent for all export ages greater or equal than three. Such pattern of survival probabilities serves as a strong indication of the prevalence of the sunk-cost mechanism in generating export patterns in homogeneous industries. Any export experience beyond the second year does not change the survival probability. The opposite is true in the differentiated industries. Every additional year of exporting slightly increases the survival probability. Thus, a learning mechanism might be the dominant factor generating persistence in exporting in the differentiated industries.

Annual survival probabilities depicted in Figure 2 have also been found in other data sets. In the context of Portuguese manufacturing firms, Amador and Opromolla (2013) find that the survival rate in the first year is around 50 percent, and subsequently increases to 80-90 percent. Using Colombian customs-level data since 1996, Eaton, Eslava, Kugler, and Tybout (2008) document similar behavior. Ruhl and Willis (2008) restrict the sample of Colombian plants to 15 employees or more and find similar survival probabilities.

Empirical patterns presented in this section are consistent with both sunk cost and age-dependence hypotheses. There is also a strong indication that the sources of persistence in exporting vary across industries. In the next section I turn to the structural estimation of sales and export participation equations to provide further evidence on the sources of persistence in exporting. To estimate the export-participation equation I select a subsample of continuously operating plants between 1979 and 1989, yielding 2,501 plant-level observations for each year I use data for the period 1981-1984 as pre-sample observations in equation (10). I use data for the period 1985-1989 as sample observations in equations (7) and (9).¹⁴

¹⁴On average, those plants amount to 37 percent of plants operating in an average year; they account for 65 percent of aggregate exports in an average year; and they comprise 61 percent of all exporters in an average year.

5. Results

This section presents results from the empirical estimation. In Section 5.1 the results from estimating the export sales equation are discussed. Overall the findings provide strong support for the age-dependence assumption. There is no substantial variation across industries in return to export experience. In Section 5.2, the results from estimating the export-participation equation are discussed. I find that export experience is an important determinant of the current export choice as implied by the model. Overall, close to a half of the value of the state-dependence parameter can be attributed to the first-year learning. In the differentiated industries the first-year learning effect is as large as four fifths.

5.1. Age-Dependence of Sales

The results from estimating the sales equation (5) are presented in Table 4. Column (1) includes the most general specification of the age dependence of export sales by including dummy variables for export ages between two and eight years (the maximum export age in the sample). The results provide strong support for the age-dependence hypothesis. Each age coefficient up to five years is statistically significant at the one percent level indicating that there exists substantial returns to export experience in the initial years of exporting. The magnitudes of the age coefficients gradually increase indicating that the effect of export experience accumulates over time. The effect of the eighth year of exporting is not statistically significant at the ten percent level indicating there are diminishing returns to export experience. Columns (2) and (3) check the robustness of results with respect to two functional form assumptions for the effect of export age on sales: quadratic and logarithmic. In both cases the effect of export age is statistically significant at the one percent level.

Column (4) explores the differences in the learning mechanism between the differentiated and homogeneous industries. The effect of the logarithm of export age is interacted with two dummy variables: one dummy variable, D_i , equals one if a plant sells differentiated products and zero otherwise. The other dummy variable, H_i , equals one if a plant sells homogeneous products and zero otherwise. Notice that there are no substantial differences in the returns to export experience on export sales between homogeneous and differentiated industries. Both coefficients are not statistically significant at

Table 4: Estimation Results: Export Sales

Explanatory Variable	(1)	(2)	(3)	(4)
Export Age _{i,t} = 2	0.201*** (0.074)			
Export Age _{i,t} = 3	0.346*** (0.100)			
Export Age _{i,t} = 4	0.356*** (0.129)			
Export Age _{i,t} = 5	0.419*** (0.161)			
Export Age _{i,t} = 6	0.434** (0.203)			
Export Age _{i,t} = 7	0.554** (0.2545)			
Export Age _{i,t} = 8	0.272 (0.337)			
Export Age _{i,t}		0.233*** (0.066)		
(Export Age _{i,t}) ²		-0.021*** (0.008)		
ln (Export Age _{i,t})			0.289*** (0.081)	0.286*** (0.091)
ln (Export Age _{i,t}) × D _i				-0.023 (0.112)
ln (Export Age _{i,t}) × H _i				0.242 (0.216)
D _i				0.289 (0.289)
H _i				-0.239 (0.692)
ln (TFP _{i,t-1})	0.205*** (0.065)	0.206*** (0.065)	0.204*** (0.065)	0.205*** (0.065)
Constant	8.607*** (1.103)	8.351*** (1.102)	8.505*** (1.097)	8.365*** (1.109)
Number of Obs.	2,743	2,743	2,743	2,743
R ²	0.874	0.874	0.874	0.874

Note: The dependent variables is the logarithm of the export sales. All regressions include industry-time and plant fixed effects.

Significance: * 10 percent, ** 5 percent, *** 1 percent.

the ten percent level. These results are consistent with the preliminary evidence presented in Figure 1 and suggest that the difference in persistence rates among differentiated and homogeneous industries documented in Table 3 might arise due to differences in sunk costs, as explored in the next section.

5.2. *Export Participation*

The estimation results are reported in Table 5. Column (1) reports the estimates of the simplest model that does not control for the firm’s age in the market. Column (2) reports the estimates of the non-parametric specification. Columns (3) and (4) report results for specifications which imposes a functional form restriction.

The estimates in Table 5 offer strong support for the age-dependence hypothesis: in column (2) each consecutive year of exporting increases the current probability of exporting. The marginal effect of each year of exporting up to 3 periods ago is positive and statistically significant. The column also implies that by the fourth year of exporting learning effect are exhausted: the marginal contribution of the fourth year is not statistically different from zero.

The decomposition result in columns (3) or (4) of Table 5 suggests that the sunk-cost effect accounts for a half of the effect of one-year lagged exporting, with the rest attributed to the age effect. Under the logarithmic parameterization of the age effect, the effect of sunk costs is 0.886 in column (4), while the total effect of one year of exporting is 1.652 from column (2). The results are similar for the quadratic form specification in column (3).

Further, in comparison to the standard estimates, the effect of sunk costs is two and a half times smaller. The proper comparison of the coefficient on one-year lagged exporting is between column (1) and column (3) or (4). The model in column (1) is typical for the literature and the effect of one-period lagged exporting is interpreted as arising solely from sunk costs. This effect is almost three times as large as the true effect of sunk costs estimated in column (3) or (4).

When controlling for export age, the variance in unobserved plant heterogeneity declines from 0.70 in column (1) to 0.19 in column (3) or 0.20 in column (4). Similarly, once the age is controlled for, there no longer is a serial correlation in unobserved firm characteristics. In contrast to the estimate in column (1) where $\rho = -0.279$ and is statistically significant at the 1 percent level, in column (4), $\rho = 0.081$ with the standard error of 0.071.

Table 5: Estimation Results: Probability of Exporting

Explanatory Variable	(1)	(2)	(3)	(4)	(5)	(6)
$Y_{i,t-1}$	2.215*** (0.103)	1.652*** (0.148)	0.963*** (0.294)	0.886*** (0.200)	2.160*** (0.112)	1.077*** (0.224)
$Y_{i,t-1}Y_{i,t-2}$		0.505*** (0.131)				
$Y_{i,t-1}Y_{i,t-2}Y_{i,t-3}$		0.416** (0.177)				
$Y_{i,t-1}Y_{i,t-2}Y_{i,t-3}Y_{i,t-4}$		0.121 (0.166)				
ExportAge $_{i,t}$			0.789*** (0.251)			
(ExportAge $_{i,t}$) ²			-0.087* (0.049)			
ln(ExportAge $_{i,t}$)				1.149*** (0.129)		0.953*** (0.151)
$Y_{i,t-1} \times D_i$					0.134 (0.109)	-0.654** (0.287)
$Y_{i,t-1} \times H_i$					0.538* (0.296)	0.242 (0.707)
ln(ExportAge $_{i,t}$) $\times D_i$						0.639*** (0.223)
ln(ExportAge $_{i,t}$) $\times H_i$						0.145 (0.502)
$\tilde{Y}_{i,t-2}$	0.324*** (0.120)	0.923*** (0.118)	0.933*** (0.117)	0.925*** (0.120)	0.313*** (0.121)	0.915*** (0.121)
$\tilde{Y}_{i,t-3}$	0.609*** (0.122)	0.767*** (0.120)	0.778*** (0.119)	0.776*** (0.120)	0.607*** (0.123)	0.770*** (0.120)
$\tilde{Y}_{i,t-4}$	0.330** (0.142)	0.509*** (0.136)	0.521*** (0.135)	0.521*** (0.136)	0.335** (0.143)	0.523*** (0.137)
ln(TFP $_{i,t-1}$)	0.412*** (0.052)	0.360*** (0.049)	0.362*** (0.048)	0.365*** (0.049)	0.413*** (0.051)	0.365*** (0.049)
Var(κ_i)	0.698*** (0.011)	0.199*** (0.014)	0.185*** (0.014)	0.203*** (0.015)	0.677*** (0.011)	0.201*** (0.015)
θ	1.713*** (0.259)	3.506** (1.600)	3.578** (1.692)	3.153** (1.444)	1.731*** (0.264)	3.132** (1.444)
ρ	-0.279*** (0.048)	0.094 (0.069)	0.091 (0.069)	0.081 (0.071)	-0.284*** (0.048)	0.078 (0.071)
Number of Obs.	22,473	22,473	22,473	22,473	22,473	22,473
Log Likelihood	-4086.01	-4055.48	-4055.42	-4055.76	-4083.38	-4049.43

Note: The table reports estimates of the dynamic random effect probit model. The dependent variable is the dummy variable for export participation in period t . Maximum Simulated Likelihood estimator is used. Standard errors are reported in parenthesis. Number of simulation draws per observation is 600.

Significance: * 10 percent, ** 5 percent, *** 1 percent.

Thus, much of the unobserved firm-level heterogeneity can be attributed to the differences in export history, that is, the firm's age in the market.

Columns (5) and (6) examine differences in the sources of export persistence across homogeneous versus differentiated industries by including interactions terms with two dummy variables, D_i and H_i , as in Table 4. Column (5) reports the estimates of an export participation model which does not control for continuous export history. The interaction term between export choice last period and the homogeneous-plant dummy variable is statistically significant at the 10 percent level indicating that there exists stronger state dependence in exporting within homogeneous industries. This finding is consistent with the general patterns of persistence in exporting presented in Table 3.

Results in column (6) indicate that much of the persistence in exporting within differentiated industries arises due to learning. The coefficient on the interaction term between the differentiated-plant dummy variable and the last period export choice is negative and statistically significant at the 5 percent level. The implied sunk costs effect of the one year of exporting in differentiated industries is 0.4, which comprises about a quarter of the total effect of one year of exporting reported in column (2). The remaining effect is due to learning: the interaction term between the differentiated-plant dummy variable and the logarithm of export age is positive and statistically significant at the one percent level. Thus, much of the state dependence in exporting within differentiated-products industries is due to a market learning mechanisms, while within homogeneous-products industries a larger portion of state dependence arises due to sunk costs. While the approach taken in this paper does not allow to numerically quantify the magnitude of sunk costs, the result are suggestive of the fact that this magnitude is overall much smaller. Furthermore, there might be substantial differences in the magnitude of sunk costs between homogeneous- and differentiated-products industries.

6. Conclusion

This paper explores the sources of persistence in exporting. There are two prevailing theories for why exporting is persistent: sunk costs and learning. Learning is modeled as the dependence of sales on export experience. In the estimation of the export sales equation, I find strong and statistically significant effects of export age on export sales. This result favors the learning

hypothesis. I further show that the dependence of current export choice on the last year’s export decision can arise due to sunk costs, learning, or both of these mechanisms, while a longer export history predicts export choice only if learning exists. In the estimation of the export-participation equation, I find that each consecutive year that a firm exports will increase that firm’s probability of exporting in the future. This finding provides strong support for the learning mechanism. While I cannot reject the sunk-cost hypothesis, I find that, when compared to the standard estimates, the effect of sunk costs in accounting for export persistence declines by sixty percent. Finally, I find that the two sources of persistence vary between homogeneous versus differentiated industries. The sunk cost component prevails in the former, while the learning component prevails in the latter types of industries. The contribution of the sunk costs to state dependence in exporting is at most a quarter in the context of differentiated industries.

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Appendix A. Proof of Proposition 1

To simplify notation, I will omit a firm’s subscript i . Notice that the Bellman Equation (2) can be simplified by including only two state variables: z_t and A_t . For the purposes of the proof, the third state variable Y_{t-1} can be omitted since its value is determined by the value of A_t . Whenever $A_t > 0$, $Y_{t-1} = 1$ and when $A_t = 0$, $Y_{t-1} = 0$. Thus, rewrite equation (2) as follows

$$\begin{aligned}
V(z_t, A_t) &= \\
&= \max_{Y_t \in \{1,0\}} \{(\pi(z_t, A_t) - f_e I(A_t = 0) + \delta E_{z_{t+1}} V(z_{t+1}, A_{t+1}), \delta E_{z_{t+1}} V(z_{t+1}, 0)\},
\end{aligned} \tag{A.1}$$

where $I(A_t = 0)$ is an indicator function which equals one when $A_t = 0$ and zero otherwise.

Part (a). The proof is by contradiction.

One needs to show that the exit threshold $z_L(A_t)$ declines as A_t rises. Suppose that it is not true. Suppose instead that $z_L(A_t)$ is increasing in A_t . Consider any two A_t s such that $A_2 > A_1 > 0$. Then, by assumption $z_L(A_2) > z_L(A_1)$. To simplify notation denote $z_L(A_2)$ by z_2 and $z_L(A_1)$ by z_1 . Since z_2 is the productivity exit threshold for a firm of age A_2 , for any $z < z_2$ a firm will exit. Consider one such z being z_1 . Thus, in state (z_1, A_2) a firm chooses not to export. From the Bellman Equation (A.1) this implies

$$\pi(z_1, A_2) + \delta E_{z'|z_1} V(z', A_2 + 1) < \delta E_{z'|z_1} V(z', 0). \tag{A.2}$$

Next, a firm in the state (z_1, A_1) is indifferent between exporting and not. Bellman Equation (A.1) implies

$$\pi(z_1, A_1) + \delta E_{z'|z_1} V(z', A_1 + 1) = \delta E_{z'|z_1} V(z', 0). \tag{A.3}$$

Combine equations (A.2) and (A.3) to obtain the following inequality

$$\pi(z_1, A_2) + \delta E_{z'|z_1} V(z', A_2 + 1) < \pi(z_1, A_1) + \delta E_{z'|z_1} V(z', A_1 + 1). \tag{A.4}$$

Since the profit function is increasing in A_t , $\pi(z_1, A_2) > \pi(z_1, A_1)$. Also, remember that since the profit function is increasing in z_t and A_t , so is the value function. Thus, $V(z', A_2 + 1) > V(z', A_1 + 1)$. Since the expectation is with respect to z' which is normally distributed (remember that z_t follows an AR1 process), $E_{z'|z_1} V(z', A_2 + 1) > E_{z'|z_1} V(z', A_1 + 1)$. Thus, equation (A.4) cannot hold and by assuming $z_2 > z_1$ we arrived to a contradiction. Thus, $z_1 > z_2$. QED

Part(b) and (c).

Let z_H be the productivity entry threshold for a firm with no prior export experience. If $f_e > 0$, Bellman Equation (A.1) implies that z_H satisfies

$$\pi(z_H, 0) - f_e + \delta E_{z'|z_H} V(z', 1) = \delta E_{z'|z_H} V(z', 0). \tag{A.5}$$

Denote this solution by z_1 . Similarly, if $f_e = 0$, z_H satisfies

$$\pi(z_H, 0) + \delta E_{z'|z_H} V(z', 1) = \delta E_{z'|z_H} V(z', 0). \quad (\text{A.6})$$

Denote this solution by z_2 .

First, I will prove that $z_1 > z_2$. The proof is by contradiction. Suppose not. Suppose that $z_1 < z_2$. Then $\pi(z_2, 0) > \pi(z_1, 0)$, and substituting $\pi(z_2, 0)$ into equation (A.5) results in the following inequality

$$\pi(z_2, 0) - f_e + \delta E_{z'|z_1} V(z', 1) > \delta E_{z'|z_1} V(z', 0).$$

Substitute for $\pi(z_2, 0)$ from equation (A.6) to obtain

$$\begin{aligned} \delta E_{z'|z_2} V(z', 0) - \delta E_{z'|z_2} V(z', 1) - f_e + \delta E_{z'|z_1} V(z', 1) &> \delta E_{z'|z_1} V(z', 0) \\ \delta E_{z'|z_1} [V(z', 1) - V(z', 0)] &> \delta E_{z'|z_2} [V(z', 1) - V(z', 0)] + f_e \end{aligned}$$

Notice that on both sides on the inequality the expectation is taken of the same function. The random variable on the left hand side however stochastically dominates the random variable on the right hand side (since by assumption $z_2 > z_1$) implying that $\delta E_{z'|z_2} [V(z', 1) - V(z', 0)] > \delta E_{z'|z_1} [V(z', 1) - V(z', 0)]$. Hence, the contradiction. Thus $z_1 > z_2$. ■

Second, the exit threshold $z_L(A_t)$ satisfies

$$\pi(z_L, A_t) + \delta E_{z'|z_L} V(z', A_t + 1) = \delta E_{z'|z_L} V(z', 0).$$

When age $A_t = 0$, the equation above becomes

$$\pi(z_L, 0) + \delta E_{z'|z_L} V(z', 1) = \delta E_{z'|z_L} V(z', 0).$$

Notice that this is the same equation as equation (A.6). Thus, if $f_e = 0$ then $z_L(0) = z_H$, and if $f_e > 0$ then $z_L(0) < z_H$. QED

Appendix B. Derivation of the Empirical Specification

To simplify notation, I will omit a firm's subscript i . I establish the following equality

$$\sum_{j=0}^{+\infty} (z_H - z_L(j)) Y_{t-1} I(A_t = j) = \beta_1 Y_{t-1} + \sum_{j=2}^{+\infty} \lambda_j \hat{Y}_{t-j},$$

where $\beta_1 = z_H - z_L(1)$, $\lambda_j = z_L(j-1) - z_L(j)$, and $\hat{Y}_{t-j} = \prod_{k=1}^j Y_{t-k}$.

Notice, that the first term in the summation on the left hand side of the equality, $(z_H - z_L(0))Y_{t-1}I(A_t = 0)$, always equals zero and therefore can be omitted: Y_{t-1} equals 1 whenever $I(A_t = 0) = 0$, and Y_{t-1} equals 0 whenever $I(A_t = 0) = 1$. For $j > 0$ manipulate the summation on the left-hand side in the following way

$$\begin{aligned} & \sum_{j=1}^{+\infty} (z_H - z_L(j))Y_{t-1}I(A_t = j) = \\ & = \sum_{j=1}^{+\infty} (z_H - z_L(1) + z_L(1) - z_L(j))Y_{t-1}I(A_t = j) = \\ & = (z_H - z_L(1))Y_{t-1} \sum_{j=1}^{+\infty} I(A_t = j) + \sum_{j=1}^{+\infty} (z_L(1) - z_L(j))Y_{t-1}I(A_t = j). \end{aligned}$$

Notice that for any $k \in \mathbb{N}$ the following equalities hold: $\sum_{j=k}^{+\infty} I(A_t = j) = I(A_t \geq k) = Y_{t-k}$. Substituting this into the previous equation one obtains

$$\begin{aligned} & \sum_{j=1}^{+\infty} (z_H - z_L(j))Y_{t-1}I(A_t = j) = \\ & = \beta_1 Y_{t-1} I(A_t \geq 1) + \sum_{j=2}^{+\infty} (z_L(1) - z_L(2) + z_L(2) - z_L(j))Y_{t-1}I(A_t = j) = \\ & = \beta_1 Y_{t-1} + (z_L(1) - z_L(2))Y_{t-1} \sum_{j=2}^{+\infty} I(A_t = j) + \sum_{j=2}^{+\infty} (z_L(2) - z_L(j))Y_{t-1}I(A_t = j) = \\ & = \beta_1 Y_{t-1} + \lambda_2 Y_{t-1} I(A_t \geq 2) + \sum_{j=3}^{+\infty} (z_L(2) - z_L(j))Y_{t-1}I(A_t = j) = \\ & = \beta_1 Y_{t-1} + \lambda_2 Y_{t-1} Y_{t-2} + \sum_{j=3}^{+\infty} (z_L(2) - z_L(3) + z_L(3) - z_L(j))Y_{t-1}I(A_t = j) = \\ & = \beta_1 Y_{t-1} + \lambda_2 Y_{t-1} Y_{t-2} + \lambda_3 Y_{t-1} Y_{t-2} Y_{t-3} + \sum_{j=4}^{+\infty} (z_L(3) - z_L(j))Y_{t-1}I(A_t = j) = \dots \\ \dots & = \beta_1 Y_{t-1} + \sum_{j=2}^{+\infty} \lambda_j \prod_{k=1}^j Y_{t-k} = \beta_1 Y_{t-1} + \sum_{j=2}^{+\infty} \lambda_j \hat{Y}_{t-j} \end{aligned}$$

which is the desired result.

Appendix C. Estimation Method

In the absence of the serially correlated errors, the model in (7) and (10) (or (9) and (10)) can be estimated using a maximum likelihood method. Assume there are J pre-sample periods. The likelihood function for plant i can be written as

$$l_i = \int_{-\infty}^{+\infty} \Pi_{t'=1}^J \Phi [(\alpha^0 + \gamma^0 X_{i,t'}^0 + \theta \kappa_i) (2Y_{i,t'} - 1)] \times \\ \times \Pi_{t=J+1}^T \Phi \left[\left(\alpha + \beta_1 Y_{i,t-1} + \sum_{j=2}^J \lambda_j \hat{Y}_{i,t-j} + \gamma X_{i,t} + \kappa_i \right) (2Y_{i,t} - 1) \right] dF(\kappa_i).$$

One can use Gaussian-Hermite quadrature Butler and Moffitt (1982) to evaluate the integral, and proceed using a standard maximum likelihood estimation.

With the autocorrelated errors the likelihood function for plant i is given by

$$l_i = \int_{-\infty}^{+\infty} [\Phi [(\alpha^0 + \gamma^0 X_{i,1}^0 + \theta \kappa_i) (2Y_{i,1} - 1)] \times \\ \times \int_{b_l(Y_{i,1})}^{b_h(Y_{i,1})} \Phi [(\alpha^0 + \gamma^0 X_{i,2}^0 + \theta \kappa_i + \rho e_{i,1}) (2Y_{i,2} - 1)] dF(e_{i,1}) \times \\ \times \int_{b_l(Y_{i,2})}^{b_h(Y_{i,2})} \int_{b_l(Y_{i,1})}^{b_h(Y_{i,1})} \Phi [(\alpha^0 + \gamma^0 X_{i,2}^0 + \theta \kappa_i + \rho^2 e_{i,1} + \rho e_{i,2}) (2Y_{i,2} - 1)] dF(e_{i,1}) dF(e_{i,2}) \times \\ \times \dots] dF(\kappa_i)$$

The evaluation of this likelihood involves the evaluation of up to T -dimensional integrals. integration up to the order of T . To address the problem of multi-dimensional integration, a maximum simulated likelihood estimator based on the Geweke-Hajivassiliou-Keane algorithm is used. The details are outlined in Keane (1994), Gourieroux and Monfort (1996), and Cemerón and Trivedi (2005). In the nutshell, for each guess of parameters, the likelihood for plant i is simulated by taking R draws of the random components $\{\kappa_i^r, e_{i,1}^r, \dots, e_{i,T}^r\}_{r=1}^R$ from the corresponding distributions. The implied simulated likelihood for

plant i is then given by

$$l_i^{sim} = \frac{\sum_{r=1}^R (\Phi[(\alpha^0 + \gamma^0 X_{i,1}^0 + \theta \kappa_i^r)(2Y_{i,1} - 1)] \times \Phi[(\alpha^0 + \gamma^0 X_{i,2}^0 + \theta \kappa_i^r + \rho e_{i,1}^r)(2Y_{i,2} - 1)] \times \dots)}{R}$$

The full sample simulated likelihood is the product of individual l_i^{sim} . Parameters are then chosen to maximize the simulated log-likelihood.

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