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Informality, Input Delays and Macrodevelopment in Sub-Saharan Africa

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À mon feu père Atchéni Rémy

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Résumé

Cette thèse en trois articles contribue à la littérature sur les défis du développement économique en Afrique subsaharienne. Deux problèmes principaux sont abordés : l'informalité des entreprises et les longs délais de dédouanement des intrants importés à la frontière.

La littérature en macro-développement sur l'informalité des entreprises dans les pays en développement a négligé la transition de l'informalité vers la formalité. En utilisant les données des enquêtes sur les entreprises de la Banque mondiale, je montre dans le premier article qu'une proportion importante d'entreprises formelles en Afrique subsaharienne étaient informelles à la création et sont passées à l'économie formelle par la suite. Les analyses empiriques montrent aussi que la proportion d'entreprises formelles autrefois informelles est positivement corrélée à l'impôt sur le bénéfice des entreprises, aux contraintes financières et aux obstacles liés à l'administration fiscale. Je développe ensuite un modèle structurel dynamique d'équilibre général d'entreprises hétérogènes où la transition de l'informalité à la formalité est possible. Dans le modèle, les entreprises sont confrontées à des contraintes financières sous la forme d'exigences de garantie. Le modèle est calibré sur les données du Nigeria et utilisé pour évaluer comment différentes politiques peuvent affecter non seulement le taux d'informalité, mais aussi la transition de l'informalité à la formalité. Les résultats montrent que la réduction des coûts de la formalité, l'amélioration de l'accès au financement et/ou de la productivité des entreprises peuvent réduire de manière significative l'informalité et améliorer la productivité globale des facteurs. De plus, la réduction de l'informalité est associée à des gains substantiels en termes de production et de recettes fiscales du gouvernement. En particulier, la réduction de l'impôt sur les bénéfices de 30 % à 15 % peut réduire le taux d'informalité de 39 points de pourcentage et augmenter le ratio recettes fiscales publiques/PIB de 8 points de pourcentage.

Le deuxième article montre que les délais de dédouanement des intrants importés sont plus longs dans les pays d'Afrique subsaharienne que dans les économies avancées. Dans certains pays, le délai moyen de dédouanement dépasse un mois alors qu'il est d'environ cinq jours ou moins en Allemagne, en Grèce, en Irlande ou en Thaïlande. Cet article montre que ces retards génèrent des perturbations des chaines d'approvisionnement et quantifie leurs effets. À cette fin, je développe un modèle dynamique d'équilibre général dans lequel les intrants importés par les entreprises sont sujets à des délais aléatoires. Après avoir calibré le modèle sur les données, je simule un scénario dans lequel le retard moyen aux frontières est réduit à une semaine ou moins. Les résultats montrent que les entreprises augmentent leurs commandes d'intrants étrangers dans le modèle de base afin de s'auto-assurer contre le risque *ex-ante* de perturbations des approvisionnements. Cependant,

la quantité agrégée d'intrants étrangers est réduite en raison des *réalisations ex-post* des retards. Dans le scénario contrefactuel, l'élimination des retards induit une augmentation de la production globale allant jusqu'à 10% et de l'emploi jusqu'à 5,8%. Ces gains sont principalement dus à une augmentation substantielle de l'utilisation d'intrants étrangers.

Le dernier article est co-écrit avec mon superviseur Immo Schott. Il approfondit l'analyse de l'impact macroéconomique des retards d'intrants aux frontières dans un modèle plus général et plus complexe qui tient compte de plusieurs dimensions d'hétérogénéité entre les entreprises. Plus précisément, le modèle économique dans cet article représente des entreprises hétérogènes du point de vue de leurs productivité, et qui diffèrent aussi de manière endogène dans leur degré d'utilisation des intrants étrangers et de la technologie de production utilisée. Il est calibré sur des données microéconomiques de l'Afrique subsaharienne. Les résultats montrent que les retards de dédouanement des intrants importés diminuent la production agrégée en raison d'une mauvaise allocation des facteurs de production et d'un nombre réduit d'entreprises qui utilisent des intrants étrangers dans la production. Nous avons trouvé aussi que les retards existants s'apparentent à une taxe de 37% sur les intrants importés. La réduction des délais aux frontières peut augmenter la production agrégée jusqu'à 14%. Les gains sont principalement dus à une réallocation des facteurs de production vers les entreprises plus productives.

Mots-clés: Entreprise informelle, entreprise formelle, formalisation, transition, contraintes financières, délais de dédouanement, intrants étrangers, perturbations, Afrique subsaharienne.

Abstract

This thesis in three articles contributes to the literature on economic development challenges in Sub-Saharan Africa. Two main problems are analyzed: informality of enterprises and imported inputs delays at borders.

The macro-development literature on informality in developing countries overlooked transition from informality to formality. Using the World Bank Enterprise Surveys data, I document in the first article that an important proportion of formal firms in Sub-Saharan Africa were informal at start and transitioned to the formal economy later on. Further empirical analysis shows that the proportion of these once-informal among formal firms is positively correlated with profit tax, financial constraint and tax administration hurdles. Then I develop a structural dynamic general equilibrium model of heterogeneous firms that accounts for the transition from informality to formality. In the model, firms face financial constraints in the form of collateral requirements. I calibrate the model to Nigeria data and use it to assess how different policies can affect not only informality rate, but also transition from informality to formality. The results show that reducing the costs of formality, improving access to finance and/or firms' productivity can significantly reduce informality and improve aggregate TFP. Moreover, reducing informality is associated with substantive gains of output and government tax revenue. In particular, reducing profit tax from 30% to 15% can reduce informality rate by 39 percentage points and increase the government tax revenue to GDP ratio by 8 percentage points.

The second article shows that time delays at borders to clear imported inputs are longer in Sub-Saharan African countries than in advanced economies. In some countries, the average clearance delay exceeds a month while it is about five days or less in Germany, Greece, Ireland or Thailand. This article argues that these delays generate input disruptions in Sub-Saharan Africa and quantifies their effects. To this end I develop a dynamic general equilibrium model where firms' foreign inputs are subject to random time delays. After calibrating the model to the data, I simulate a scenario where the average border delay is reduced to one week or less. I found that firms place higher foreign input orders in the baseline model to self-insure against *ex-ante risk* of input disruptions. However, aggregate foreign input is lower in steady state due to *ex-post realizations* of the delays. In the counterfactual, eliminating the delays induces aggregate output to increase by up to 10% and employment by up to 5.8%. These gains are driven mainly by a substantial increase of foreign inputs use.

The last article is co-authored with my supervisor Immo Schott. It furthers the analysis of the macroeconomic impact of inputs delays at borders in a more general and a more complex model to account for many dimensions of firms' heterogeneity. Specifically, the model economy features heterogeneous firms that endogenously differ in the degree to which they use foreign capital goods. It is calibrated to micro-level data from Sub-Saharan Africa. The results show that delays in imported capital goods lower aggregate output through factor misallocation and an insufficient number of firms that use foreign capital in production. We also find that the existing delays are akin to a 37% tax on imported capital goods. Reducing border delays can increase aggregate output by up to 14%. The gains are mainly due to a reallocation of economic activity towards more productive firms.

Keywords: Informal firm, formal firm, formalization, transition, financial constraints, border delays, foreign inputs, disruption, Sub-Saharan Africa.

Article 1

Informality as a stepping stone in developing countries: the role of financial constraints*

Idossou Marius ADOM†

Abstract.– The macro-development literature on informality in developing countries overlooked transition from informality to formality. Using the World Bank Enterprise Surveys data, I document that an important proportion of formal firms in Sub-Saharan Africa were informal at start and transitioned to the formal economy later. Cross-country analysis shows that the proportion of once-informal among formal firms is positively correlated with financial constraint and tax administration hurdles. Then I develop a structural dynamic general equilibrium model of heterogeneous firms that accounts for the transition from informality to formality. In the model, firms face financial constraints in the form of collateral requirements. I calibrate the model to Nigeria data and use it to assess how different policies can affect not only informality rate, but also transition from informality to formality. The results show that reducing the costs of formality, improving access to finance and/or firms' productivity can significantly reduce informality and improve aggregate TFP. Moreover, reducing informality is associated with substantive gains of output and government tax revenue. In particular, reducing profit tax from 30% to 15% can reduce informality rate by 39 percentage points and increase the government tax revenue to GDP ratio by 8 percentage points.

Key words: Informal firm, formal firm, formalization, transition, financial constraints.

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1 Introduction

Informality is a key characteristic of poor and developing countries. According to the International Labour Organization (2019), 8 economic units out of 10 are informal worldwide, and 47.2% of global employment was provided by informal sector economic units in 2019. Although the phenomenon also exists – to a lesser extent – in developed countries, it often draws attention in poor and developing countries where the relative size of the informal economy is astonishing. Informal firms account for up to about half of the overall economic activity in developing countries (La Porta and Shleifer, 2008). Yet the definition of informality is not unequivocal in the literature. This paper is about *firms informality* as defined by the World Bank Enterprise Surveys (WBES) framework: a firm is formal when it is registered with the tax authorities and informal otherwise.

In structural models of informality in the macro-development literature, firms are permanently either formal or informal (Ulyssea, 2018; D'Erasmo, Moscoso Boedo, and Senkal, 2014; D'Erasmo and Moscoso Boedo, 2012; Galiani and Weinschelbaum, 2012; Rauch, 1991). These models do not account for transition from informality to formality partly because some previous data show that almost all formal firms in India and Brazil have always been formal (La Porta and Shleifer, 2008, 2014; Ulyssea, 2018). In this paper I show that this fact does not hold in Nigeria in particular and in Sub-Saharan Africa (SSA) in general because a significant proportion of formal firms began as informal and registered later on.[2] These *once-informal firms* are smaller, grow slower and are more financially constrained compared to firms that have always been formal. In SSA, financial constraints and multiple meetings with tax officials affect positively the proportion of *once-informal firms* among formal firms. I build a model of heterogeneous entrepreneurs that face financial constraints on the capital market and choose rationally to operate either formally or informally. Formal firms pay taxes while informal firms do not. Nevertheless, the latter face potential fines and more severe financial constraints. Importantly, the model accounts for transition from informality to formality. Consistent with the data, some firms in the model use informality as a stepping stone. They are highly productive and would be formal in the absence of financial constraints and taxes. But with too small assets, entrepreneurs start informal, micro or small enterprises, and accumulate assets in order to grow and formalize when it becomes too costly to operate informally. Better access to finance for formal firms provides an extra incentive to formalization. I use the model to simulate the effects of different formalization incentive policies. The results show that reducing the costs of formality, improving access to finance and/or firms' productivity can significantly reduce informality and improve aggregate TFP. Moreover, reducing informality is associated with substantive gains of output and government tax revenue. In particular, reducing profit tax from 30% to 15% can reduce informality rate by 39 percentage points and increase the government tax revenue to GDP ratio by 8 percentage points.

One would care about informality because it relates to many economic problems, including

[2] In a survey carried out in downtown Lima, Peru, one third of the firms reported that they are new and have not had the time to start the registration process (Jaramillo, 2013). That suggests that some may actually plan to be formal at a certain point though they started informally.

efficiency, government tax revenue, and fiscal equity (La Porta and Shleifer, 2014, 2008; Levy, 2008; Maloney, 2004; Farrell, 2004). First, informality creates misallocation of resources from productive formal firms towards unproductive informal firms because the latter avoid regulations and face relatively lower marginal costs (Hsieh and Klenow, 2009). Second, tax avoidance lowers the government revenues. Third, informality raises social fairness issues as only formal firms contribute to public goods and services by paying taxes. In addition, it is documented that entrepreneurs and workers of informal firms are generally worse off because they earn less than their *vis-à-vis* of formal firms and lack social security or protection (International Labour Organization, 2019; Farrell, 2004). Therefore, it seems desirable to get rid of informality.

To tackle informality it is necessary to understand its causes and dynamics. In that perspective many views of informality emerge from the literature. According to the *de Soto view*, the informal economy is a reservoir of untapped resources kept back by poor regulations (de Soto, 1989, 2000; Kelmanson, Korolai, and Leandro, 2021). Schneider and Enste (2000) argue that a growing shadow economy can be seen as the reaction of individuals who feel overburdened by the State and who choose the "exit option" rather than the "voice option". Hence, the cure for informality is good governance and sound institutions (Johnson, Kaufmann, and Zoido-Lobatón, 1998). A second school of thought called the *parasitic view* holds that informal enterprises are productive enough to operate formally. They choose to be informal only to avoid taxes (Farrell, 2004). In this line of thought Maloney (2004) views the informal sector in Latin America as an unregulated micro entrepreneurial sector rather than a disadvantaged residual of segmented labor markets. According to this view, there must be strict enforcement to eradicate informality. A third view is the *survival view* according to which informal firms are so unproductive that they would not survive if they were to incur the formality costs (Levy, 2008; La Porta and Shleifer, 2008, 2014; Kelmanson et al., 2021). This view is often the basis for recommendations such as small firms subsidies, tax cuts and entrepreneurial training (David, Lambert, and Toscani, 2021). Guha-Khasnobis, Kanbur, and Ostrom (2006) report a view called *structuralism* according to which capitalist firms in the formal economy reduce their input costs, including labor costs, by promoting informal production and employment relationships with subordinated economic units and workers. It is important to note that there may be some truth to each of these views but none accounts wholly for informality. Therefore, they can coexist in an economy as shown in Ulyssea (2018). Moreover, a policy may suit to enforce informal firms that match one view but harm others that match another view. For example, strict enforcement may force *parasite* informal firms to formalize but may force out *survival* ones that provide millions of households with livelihood. I contribute to that literature by showing that informality can be a step in the entrepreneurial process for some firms. Highly productive but relatively poor entrepreneurs start a business by running informal firms. They accumulate assets, grow their business, and formalize later. Others may also learn entrepreneurship by doing, become more productive and formalize. They are *temporary* informal firms. For them, a suitable policy may be to ease access to finance, reduce the tax burden for new formal firms or/and provide productivity-enhancing training.

This paper is also related to the literature on firms financial constraints. Bernanke, Gertler, and Gilchrist (1996, 1999) developed the *financial accelerator*, a concept meaning that worsening credit-market conditions amplify adverse shocks to the economy. Since, the literature has emphasized the important role of financial constraints for firm dynamics, productivity and allocation of resources (Cooley and Quadrini, 2001; Musso and Schiavo, 2008; Banerjee and Moll, 2010; Campello, Graham, and Harvey, 2010; Buera and Shin, 2011; Buera, Kaboski, and Shin, 2011; Midrigan and Xu, 2014; Crouzet, 2018; Cao and Leung, 2020; Karabarbounis and Macnamara, 2021) and for economic development (Elenev, Landvoigt, and Van Nieuwerburgh, 2021; Moll, 2014; Buera and Shin, 2013). In the case of developing countries, Banerjee and Duflo (2014) test whether firms are really financially constrained in India and conclude that many of them must have been severely credit constrained. In general, financial markets tend to be segmented along formal/informal lines in developing countries, unlike labor markets (Pratap and Quintin, 2008). Ngalawa and Viegi (2013) further show that formal and informal financial markets in developing countries tend to be complementary and can feature very different patterns for interest rates. Ranasinghe and Restuccia (2018) find that financial frictions lower output by 20% in Colombia while Arellano, Bai, and Zhang (2012) propose a model where financial frictions drive firm growth and debt financing through the availability of credit and default risk to explain the observed cross-country variations in firm size, leverage and growth. In this paper, I model financial constraints as collateral requirements (Steijvers and Voordeckers, 2009; Banerjee and Moll, 2010; Buera and Shin, 2011, 2013; Moll, 2014). Importantly, I leverage the empirical facts to distinguish between the financial constraints of formal and informal firms in the spirit of D'Erasmo and Moscoso Boedo (2012), Mitra (2013) and D'Erasmo et al. (2014).

Finally, the paper is also related to the literature on the relationship between financial development and informality. This strand of the literature is rather sparse. D'Erasmo and Moscoso Boedo (2012) show that a low degree of debt enforcement and high costs of formality are associated with low allocative efficiency and large output shares produced by low productivity, informal sector firms. Mitra (2013) analyzed how informality affects the relationship between financial development (FD) and consumption-to-income ratio volatility. At low levels of FD, informality causes relative consumption volatility to increase because it obstructs consumption smoothing, while at higher levels of FD informality lowers volatility through its effect on the working capital requirement. I contribute to that literature by showing that financial development also fosters transition of existing informal firms to formality.

The rest of the paper is organized as follows. In section 2 I present the data and empirical findings on transition from informality to formality in SSA. Section 3 presents the model and section 4 the calibration strategy and the results of counterfactual analyses. Section 5 concludes the paper.

2 Data and empirical findings

The microdata used in this paper is from the World Bank Enterprise Surveys (WBES) for 41 SSA countries between 2009 and 2020. The calibration in section 4 .2, in particular, uses data for Nigeria 2014/15.[3] The WBES involves a nationally representative sample of formal, non-agricultural, private firms. It considers as formal all firms that are registered with tax authorities. The survey is cross-sectional. For some countries, it is repeated two or three times in different years. In this paper, I use the latest data available for each country. The paper also uses data from the Doing Business database and from the World Development Indicators (WDI). All the data sets are from the World Bank, publicly and freely available.

2 .1 Transition from informality to formal economy

Structural models of informality in the literature have a common feature: formal firms start formal, and informal firms never become formal. This modeling choice has been justified by the fact that in the data almost all formal firms started formally and have never been informal (La Porta and Shleifer, 2008, 2014; Ulyssea, 2018). However, I find otherwise. As shown in Table 1.1, near 31% of the Nigerian formal firms were not registered at their start but did it later on. I call them "*switchers*". This proportion is significant and far above the proportion (less than 10%) usually reported in the literature. These switcher firms account for more than 25% employment and for about 9% of micro, small and medium size formal firms sales.

Table 1.1: Relative importance of once-informal among formal firms

	R	NR	Total
Observations	1766	716	2 482
Prop. of firms (%)	69.27	30.73	100
Prop. of firms with fewer than 100 employees (%)	69.46	30.54	100
Prop. employment (firms with fewer than 100 employees) (%)	74.16	25.84	100
prop. sales (firms with fewer than 100 employees) (%)	91.10	8.90	100
Employment (Avg.)	20.48	13.51	18.40
Size at start (Avg.)	13.11	9.46	12.02
Avg. yearly growth of employment (%)	6.43	5.96	6.31
Age	15.22	17.25	15.75

Notes. Table compares firms that started as formal and those that started as informal. All firms are formal. Column R is for firms that were registered at start and column NR for firms that were not registered at start. Source: WBES and author's calculations.

In addition, Table 1.2 shows that transition form informality to formality in Nigeria is not driven by the sector composition of the economy. Namely, the proportion of switchers among formal firms

[3] For Nigeria, the WBES has been conducted as repeated cross-sectional surveys in 2007, 2010 and 2014. Only the 2014 survey has been conducted under the WBES internationally harmonized framework. As consequence, the 2007 and 2010 data are of lesser quality for this study with respect to some key variables like the sampling weight, whether the firm is registered at start or not and the year the firm registered formally. Therefore, I use the 2014 survey data.

is sizable across all sectors. However, the phenomenon is over-represented in IT and retail sectors while it is under-represented in the construction sector.

Table 1.2: Transition by sector

	Obs.	Prop. of firms	Prop. R	Prop. NR
Manufacturing	1427	36.83	72.34	27.66
Retail	451	17.44	60.5	39.5
Wholesale	153	5.67	64.71	35.29
IT	41	0.85	48.83	51.17
Hotel and restaurants	247	13.12	70.5	29.5
Construction	52	0.85	80.39	19.61
Transportation	304	25.23	71.43	28.57
Total	2675	99.99	69.27	30.73

Notes. Proportions are weighted. Table compares firms that started as formal and those that started as informal across sectors. All firms are formal. R stands for firms that were registered at start and NR for firms that were not registered at start. Source: WBES and author's calculations.

2 .2 Age at registration

About 69% formal firms started formally. For the firms that started informally and formalized later, the median age at registration is 4 years and the average 6.2 years. Figure 1.1 shows the overall distribution of the age at registration conditional on not being formalized at start. It is worth noting that the legal framework sometimes provides new firms with an exemption from paying taxes. It is not clear what the provisions were back in the years before the survey data is collected, but under the Nigeria Startup Act 2022, start-up companies may request to be exempted from payment of income tax for a maximum period of 5 years, three years initially and renewable for an additional two years. In addition, firms with turnover of less than NGN 25 million are not required to pay corporate tax, but a minimum income tax. We can be assured that the transitions observed in the data result from some dynamics definitely different from legal exemptions for two reasons. First, no firm is legally exempted from *registering* with tax authorities, but from *paying taxes* under the conditions mentioned previously. Second, the median and average ages at registration of switchers in the data show that these firms remain informal for longer than any exemption.

2 .3 Employment and growth

Table 1.1 shows the average number of full time employees in firms that were registered at start and those that were not, at their start and by the time of the survey (2014/15), as well as the average yearly growth of employment. As one can see, the average starting size of the firms that were registered at their start is bigger than that of those that were not registered. The same pattern holds for the average size of the firms by the time of the survey. However, the average

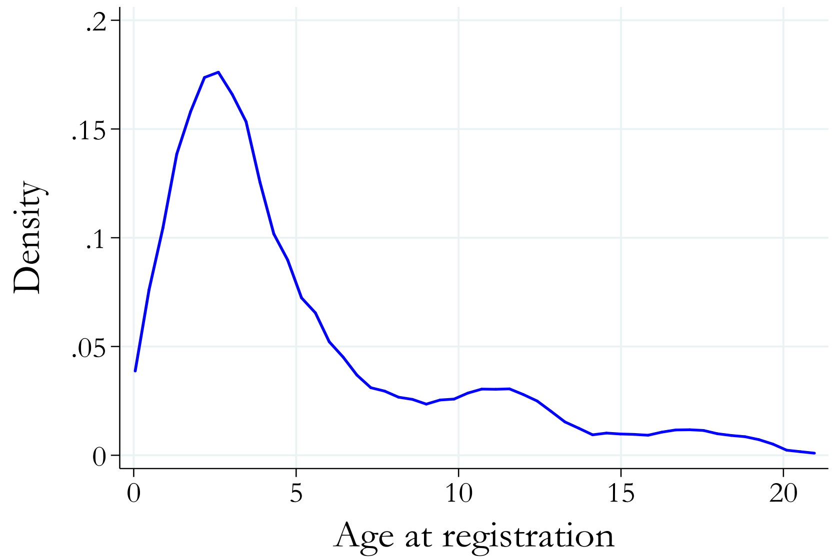

Figure 1.1: Age at registration. Figure shows the distribution of age of firms that started as informal when they became formal. Data source: WBES.

yearly growth of employment is comparable between the two groups, though the firms that were registered at start tend to grow slightly faster than those that were not.

2 .4 Access to external sources of financing

The data show that the proportion of firms that take bank loans to finance either working capital or investment projects is unevenly in favor of the firms that were registered at start (figure 1.2). Indeed, the proportion of firms registered from start that took bank loans to finance working capital (respectively investment project) is 19.5% (respectively 8.6%) against 13.6% (respectively 4.5%) for the firms that were not registered at their start. In the same vein, table 1.3 shows that the proportion of working capital and investment financed with internal resources and bank loans tend to be higher for the firms that registered from start. On the other hand, the firms that did not register from start declare higher proportion of working capital and investment financed with loans and resources from informal lenders and family members.

All these suggest that being registered (from start) is correlated with access to bank financial resources. However, as all the firms in the WBES have become formal by the time of the survey, there is clearly a selection bias because there are certainly many other informal firms that never formalize. Before looking at the still-informal sector of the economy in section 2 .5 , I look at the access to bank financing of the firms by their age since registration on Figures 1.3 and 1.4.

One can notice a decreasing relationship between the age since registration and both the proportion of firms that took bank loans to finance investment and the proportion of investment financed with bank loans. The more recently the firms were registered the more they take bank loans to finance investment projects. This suggests that before registering, they had unmet needs for external financial resources. When they formalize, they gain access to bank loans, which they use most. As they age, they accumulate internal resources or diversify their financial sources and begin to rely less on bank loans.

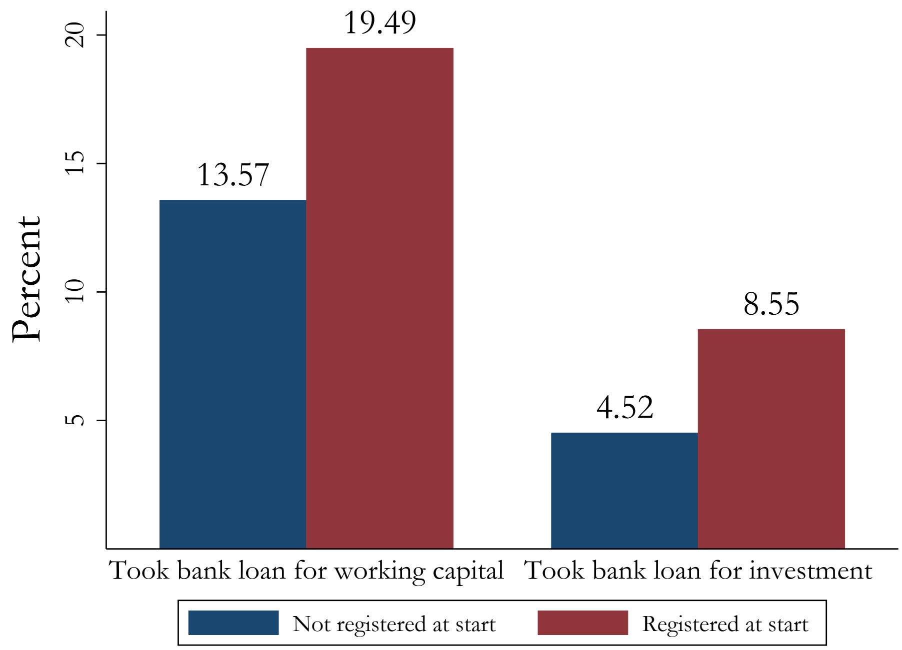

Figure 1.2: Bank loans take-up rate. Figure shows the proportion of firms that took bank loans to finance either working capital or investment projects, and compares firms that started as informal and those that started as formal. All firms are formal. Data source: WBES.

Table 1.3: Firms' financing sources

Percentage financed with ...	Working capital			Fixed capital investment		
	R	NR	All	R	NR	All
Internal funds or retained earnings	69.5	59.2	66.4	30.5	18.8	26.0
Owner personal contribution or issued new equity shares	-	-	-	9.4	4.8	7.7
Borrowing from banks	4.5	3.0	3.9	2.3	0.7	1.7
Borrowed from non-bank financial institutions	2.9	5.8	3.6	1.2	1.0	1.1
Purchases on credit from suppliers and advances from customers	6.6	6.6	7.0	2.4	2.5	2.3
Other (e.g. moneylenders, friends, relatives, factoring, etc)	16.6	25.4	19.2	11.0	45.9	21.9

Notes. Table shows the proportion of firms' working capital and fix capital investment financed by different means. All firms are formal. Columns R are for firms that were registered at start and columns NR for firms that were not registered at start. Data source: WBES

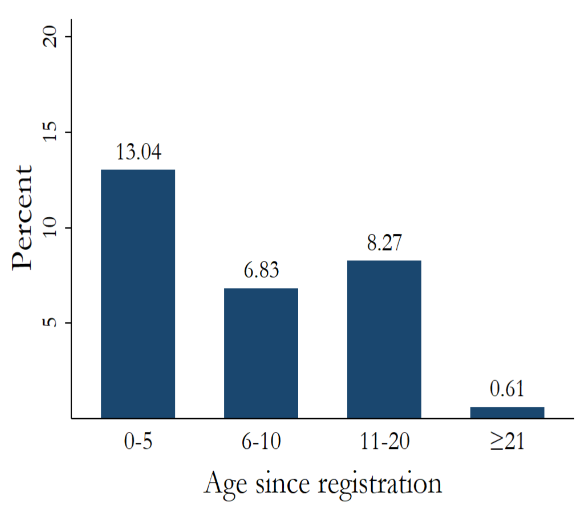

Figure 1.3: Proportion of firms that took bank loan to finance investment, by age since registration. Only firms that were not registered at start. Data source: WBES.

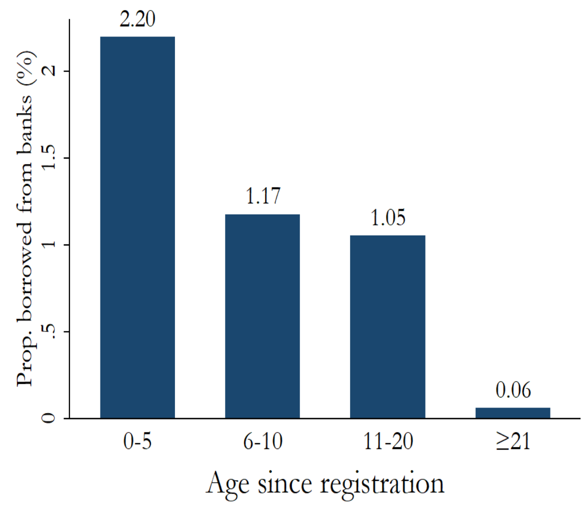

Figure 1.4: Proportion of firms' investment financed with bank loans, by age since registration. Only firms that were not registered at start. Data source: WBES.

Overall, financial constraints affect firms that were not registered from start more than those that were (Figure 1.5).

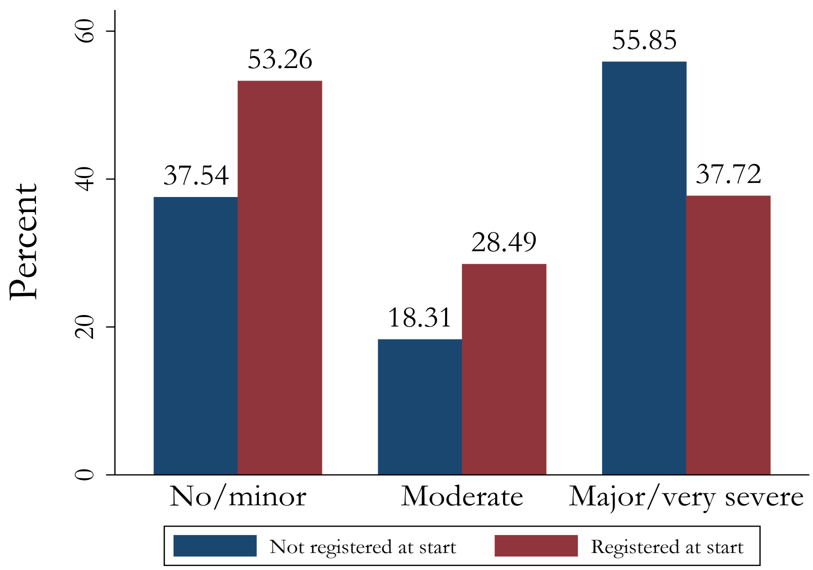

Figure 1.5: Severity of financial constraints by registration status at start. The figure shows the proportion of firms that report that financial constraints are no, minor, moderate, major or very severe obstacle. Source: WBES data and author's calculations.

2 .5 Informal firms

The firms described in the previous sections with the WBES data are all formal firms by the time of the survey. They are therefore different from firms that never formalized. A large strand of the literature documents the characteristics and the dynamics of the informal economy. According to Pratap and Quintin (2008) informal firms consist of small-scale, self-financed and unskilled labor intensive economic activities. In the same line of thought La Porta and Shleifer (2008, 2014) find that unofficial firms tend to be smaller, less productive, and younger than formal firms. Typically, most small firms in developing countries have only one or two workers consisting of the owner and at most one other paid worker (Bruhn and McKenzie, 2014; Jaramillo, 2013; de Mel, McKenzie, and Woodruff, 2010). Very often, the informal economy entrepreneurs and workers would prefer paid employment but are unable to find formal wage jobs (Fernández and Meza, 2015; La Porta and Shleifer, 2014; de Mel et al., 2010).

Micro-data on informal firms in Nigeria are very rare and hard to find. Onwe (2013) reports a survey carried out by the Central Bank of Nigeria (CBN), in collaboration with the Nigerian Institute of Social and Economic Research (NISER) and Federal Office of Statistics (FOS) in 1998 (henceforth CBN/NISER/FOS Informal Sector Survey, 1998). On the other hand, the Global Findex database [4] is the world's most comprehensive data set on how adults save, borrow, make payments, and manage risk. It provides information on whether individuals have borrowed from banks or other financial institutions for business purposes. I use the 1998 CBN/NISER/FOS Informal Sector Survey information from Onwe (2013) and the 2017 Global Findex database to infer some characteristics of the informal firms, with respect to their size and access to bank financing.

Size.– Table 1.4 below shows the size and employment distribution of informal firms in the manufacturing sector. No doubt they are very different from the formal firms. In fact, the average size of the firms is only 1.6, with more than 71% of them having only one employee. Firms of five employees or less account for about 88% informal enterprises employment in the sector.

Table 1.4: Size distribution of informal firms in the manufacturing sector.

Size	1	2	3	4	5	6-10	11-20	≥20	Total
Prop. of firms (%)	71.4	14.2	7.6	3.2	1.5	1.6	0.3	0.1	100.0
Number of employees	1. 50	0.62	0.48	0.26	0.16	0.28	0.08	0.06	3. 44
Prop. of employment (%)	43.57	17.97	14.08	7.57	4.69	8.16	2.28	1.69	100.00
Number of firms	1. 51	0.30	0.16	0.07	0.03	0.03	0.006	0.002	2.11
Avg. Size									1.6335

Notes. Table shows the size distribution of informal firms in the manufacturing sector in Nigeria. Number of employees and number of firms are in millions. Source: Onwe (2013), based on CBN/NISER/FOS Informal Sector Survey, 1998, and the author's calculations.

Access to external finance.– The Global Findex database consists of individual-level data, as opposed to firm-level data. I use non-wage earners to proxy the informal economy employees as in Azanaw and Perez-Saiz (2021). Not every informal employee owns an informal enterprise, but as

[4]See https://globalfindex.worldbank.org/

shown in the previous section, most informal firms count only one employee – the owner. Therefore, the vast majority of the non-wage earners are entrepreneurs of the informal economy (Azanaw and Perez-Saiz, 2021; International Labour Organization, 2018).

Table 1.5: Borrowing behaviors of wage earners and non-wage earners.

	Overall prop.	Borrowed at all	Borrowed for business purposes	Borrowed from financial institutions	Borrowed from financial institutions for business purposes
Non-wage earners	83.89%	42.31%	12.93%	3.90%	1.76%
Wage earners	16.11%	58.54%	12.02%	10.50%	1.76%

Notes. Table shows the proportion of wage earners and non-wage earners that borrow money. Source: Nigeria's 2014 Findev data and author's calculations.

Table 1.5 shows that only 1.76% of non-wage earners borrowed from financial institutions for business purposes. More broadly, 12.9% of them took a loan from any source for business purposes. These statistics show that informal firms may face more restrictive financial constraints compared to formal enterprises data in figure 1.2 and table 1.3. More generally, it is established in the literature that informal firms have almost no access to regular external finance like bank loans, not only because they are informal (Onwe, 2013; La Porta and Shleifer, 2008, 2014; Banerjee and Duflo, 2014), but also because they are often very small (Bernanke et al., 1996; Atkin and Donaldson, 2021). In the same vein, Atkin and Donaldson (2021) document that capital distortions are larger for small (20%) and informal firms (22%) than for large firms (16%). Mitra (2013) argues that informal sectors usually find it difficult to borrow in formal credit markets because they hide all or part of their income in order to evade taxes and other forms of regulatory burden.

2 .6 Transition, financial constraints and regulations across Sub-Saharan Africa

Is Nigeria the only country where a significant proportion of formal firms started as informal? That seems not to be the case. As shown in table A.1 in the appendix, in many other SSA countries, the proportion of formal firms that started as informal is significant. That proportion is above 10% in 27 countries, and above 20% in 10 of 41 countries for which data is available. The country with the highest share of *switchers* is Angola with 35.3%.

To investigate the determinants of *using informality as a stepping stone*, I estimate the following equation in the cross-sectional.

$$Y_i = \beta_1 Fin\_Con_i + \beta_2 Taxes_i + \beta_3 Fisc\_Admin_i + \beta_4 Form\_costs_i + \beta_5 Corruption_i + \varepsilon_i \quad (1.1)$$

Y_i, the dependent variable is the proportion of *switchers* in country i. The explanatory variables include financial constraints, taxes, efficiency of the fiscal administration, regulations and corruption. I proxy financial constraints by the proportion of firms that report that financial constraints are a major or very severe obstacle. Taxes include the rates of profit tax, labor tax and contributions to social protections. The efficiency of the fiscal administration is measured by the number of taxes firms pay, and the number of meetings firms have with tax officials in a year. Regulations are proxied by the cost of formalizing a business as proportion of income per capita and by the time needed to formalize a business (in days) while corruption is measured by the proportion of firms expected to give gifts (i.e, bribe) in meetings with officials.There is no constant in the regression equation (1.1) because the variables are standardized. The regressions are not meant to have a causal interpretation but only provide a general pattern.

I take Y and Fin_Cons for the latest WBES data available. For $Taxes$, $Fisc\_Admin$, $Form\_costs$ and *corruption*, I take the average of the available data per country between 1960 and 2021. While $Form\_costs$ is taken from the Doing Business data, the remaining variables are from the World Development Indicators database. The results of the regressions are shown in Table 1.6.

Table 1.6: Determinants of *informality as a stepping stone*

	(1)	(2)	(3)	(4)	(5)
Financial constraints	0.3237*	0.3752**	0.3741**	0.3715**	0.3653**
Taxes (profit)	0.2692	0.2324	0.2321	0.2336	0.2230
Taxes (Labor)	0.1887	0.1737	0.1734	0.1679	0.1940
Nb Taxes		−0.1572	−0.1575	−0.1527	−0.2219
Nb meeting with tax officials		0.4287***	0.4291***	0.4307***	0.3603**
Entry cost (money)			0.0037	0.0047	−0.0396
Entry cost (time)				−0.0105	0.04785
Corruption					0.2068
Obs	40	40	40	40	40
Fisher statistics (F)	2.37	4.03	3.26	2.72	2.63
Prob > F	0.0865	0.0054	0.0121	0.0244	0.0248
Adj R-squared	0.09	0.2748	0.2535	0.2310	0.2453

Notes: Table reports OLS regression coefficients. The dependent variable is the proportion of firms that started as informal in total formal firms. The analysis is cross-sectional for a sample of Sub-Saharan African countries. The explanatory variables are standardized. *, ** and *** mean statistically significant to the levels 10%, 5% and 1% respectively. See the text for data sources.

According to the results, financial constraints and the number of meetings with tax officials impact positively the proportion of *switchers* among formal firms. Because they increase the marginal cost of firms, some potential formal entrepreneurs delay formalization probably till the marginal cost of informality becomes higher. Then they switch from informal to formal enterprises. On the other hand, the effect of profit tax, payroll tax, entry costs and corruption are positive but not statistically significant. These results are consistent with the literature. La Porta and Shleifer (2008) found that registration procedures and regulations rank lower as obstacles to doing business among both formal and informal firms, while access to finance, taxes and tax administration are perceived as the biggest problems. In the same line, some papers have found that lowering formalization costs does not foster formalization of existing firms (de Andrade, Bruhn, and McKenzie, 2016; de Mel, Mckenzie, and Woodruff, 2013).

In sum, the data show that the proportion of *switchers* among formal firms is higher in SSA than in the extant literature. I show furthermore that the proportion of switchers is positively related to financial constraints, profit tax and some administrative hurdles. In the following, I build a structural model of heterogeneous firms that choose endogenously to formalize at start or later, or to remain informal forever. The model results are consistent with the empirical findings. Therefore, I use the model to perform several counterfactual analyses.

3 Model

Time is discrete. The economy consists of four types of agents: entrepreneurs of micro, small and medium size enterprises, a firm representative of large corporate enterprises, a representative household, and a government. Entrepreneurs operate formal and informal firms, produce homogeneous goods on a competitive market, and earn profits. The representative household is also a hand-to-mouth consumer, whose revenue consists only in labor income. It supplies labor by working in the entrepreneurs' firms and in the large corporate firm. The government redistributes resources through taxes and transfer activities. The model builds on the span-of-control framework (Lucas, 1978) modified to account for informality.

3 .1 Entrepreneurs

There is a continuum of entrepreneurs. An entrepreneur owns and runs a firm, earns a profit and makes consumption and saving decisions, with the objective to maximize lifetime utility.

Preferences.– Entrepreneurs have constant relative risk (CRRA) preferences, and discount future with the parameter β. The utility function of entrepreneurs is given by equation (1.2) where c_t is the entrepreneur's goods consumption of at period t.

$$u(c_t) = \frac{c_t^{1-\gamma}}{1-\gamma}, \qquad \gamma > 0 \tag{1.2}$$

Technology.– Entrepreneurs are heterogeneous in their productivity, ε, and in their asset holding, a. The productivity is governed by a first-order Markov process with autocorrelation ρ_ε and standard deviation σ_ε.

$$\log(\varepsilon_t) = \rho_\varepsilon \log(\varepsilon_{t-1}) + \sigma_\varepsilon \eta_t \tag{1.3}$$

where $\eta_t \sim \mathcal{N}(0,1)$ for all $t > 0$. Let $H(\varepsilon_{t+1}|\varepsilon_t)$ denote the conditional distribution of a firm's productivity, and $H(\varepsilon)$ the associated invariant distribution.

They combine labor and capital inputs to produce a homogeneous good, according to the technology:

$$y = f(\varepsilon, k, l) = \varepsilon \left(k^{\alpha} l^{1-\alpha}\right)^{\nu}, \;\; 0 < \nu < 1, \;\; 0 < \alpha < 1 \tag{1.4}$$

where ν is the span-of-control parameter. Accordingly, ν represents the share of output going to the variable factors. Of this output, fraction α goes to capital and $1 - \alpha$ goes to labor (Buera and Shin, 2013).

Labor is hired on a spot market from the representative household, while capital is raised each period by the means of own asset and borrowing. The financial market is imperfect, and the entrepreneur ability to borrow is constrained in the form of collateral requirement as described below. I assume homogeneous labor across formal and informal units (Maloney, 2004; Pratap and Quintin, 2008; Mitra, 2013).

Financial constraints.– Capital is raised each period on a spot market. The entrepreneur can borrow on the financial market where he faces a rental cost and a market imperfection. I represent the financial market imperfection in the form of a collateral constraint as in Moll (2014) and Buera and Shin (2013). As discussed by these authors, under some assumptions, the collateral requirement representation is equivalent to the costly state verification (CSV) framework that is also used in the literature (Cooley and Quadrini, 2001; Bernanke et al., 1999, 1996). Specifically, the amount of capital that the entrepreneur raises cannot exceed a cap that is proportional to his own asset holding at that period (Bahaj, Foulis, and Pinter, 2020).

$$k_t \leq \lambda_j . a_t \;, \; j = i, f. \tag{1.5}$$

In addition, I assume that $1 \leq \lambda_i < \lambda_f < \infty$. This condition reflects the fact that formal and informal firms do not face the same challenge on the financial market (Pratap and Quintin, 2008; Mitra, 2013). As shown in the data section, informal firms have almost no access to external sources of finance while formal firms have more, yet limited, access. Entrepreneurs' assets are restricted to the discrete set $\mathrm{A} = \{a_1 < a_2 < \cdots < a_n\}$.

Formal or informal firm.– Firms can be of two types: formal or informal. Consistent with Maloney (2004) and de Mel et al. (2013) the choice of a type is endogenous, based on a rational analysis of the costs and benefits of being formal. Importantly, informal firms can become formal if optimal to do so, but formal firms cannot become informal. In addition to a sunk cost of formalization, ξ, incurred once for all, formal firms must pay a payroll tax τ_w and a revenue tax τ_y each period.[5] The profit function of a formal firm can be written as follows.

[5]The legal fiscal framework in Nigeria is as follows. The federal government profit tax rate is 30% if gross turnover is NGN 100 million or greater, 20% if it is NGN 25 million or greater but less than NGN 100 million, and 0% otherwise (i.e if gross turnover is less than NGN 25 million). For companies with no taxable profits, they are liable to a minimum tax of 0.5% of gross income. Some new companies may request to be exempted from payment of

$$\Pi_f(\varepsilon_t, a_t) = \underset{k_t, l_t}{max}\left\{(1-\tau_y)\varepsilon\left(k_t^{\alpha} l_t^{1-\alpha}\right)^{\nu} - (1+\tau_w)w_t.l_t - (r_t+\delta).k_t \text{ s.t. } k_t \leq \lambda_f.a_t\right\} \quad (1.6)$$

Labor and capital markets are competitive. The price of the labor is w_t, and the user cost of the capital input is $r_t + \delta$. Therefore, r_t is the rental interest rate and δ the depreciation rate of the capital.

On the other hand, informal firms do not pay any tax because they do not abide by the regulations. However they face potentially a cost of fine in the event they are caught by the authorities. In the spirit of Ulyssea (2018) I assume that the expected cost of fine, $C_i(k) = \tau_i(k) \cdot F_i(k)$, is increasing and convex in the size of the firm as captured by its capital. With probability $\tau_i(k)$ increasing in the level of the firm's capital k the firm can be caught by the authorities. $\tau_i(.)$ follows an exponential distribution:

$$\tau_i(k) = 1 - \exp(-\theta k)\ ,\ \theta > 0. \quad (1.7)$$

If caught, the fine cost $F_i(k)$ is increasing and convex with respect to the size k.

$$F_i(k) = \psi k,\ \psi > 0 \quad (1.8)$$

The profit function of an informal firm is therefore given by:

$$\Pi_i(\varepsilon_t, a_t) = \underset{k_t, l_t}{max}\left\{\varepsilon_t\left[k_t^{\alpha} l_t^{1-\alpha}\right]^{\nu} - w_t l_t - (r_t+\delta)k_t - C_i(k) \text{ s.t. } k_t \leq \lambda_i.a_t\right\} \quad (1.9)$$

Note that informality enforcement does not force informal firms out or even systematically imply formalization. It is possible for an informal firm caught by the government to pay the fine and continue as informal firm if optimal (from the firm's perspective) to do so. This somehow loose enforcement is in line with the reality in developing countries. By contrast, some have assumed in the literature that an informal firm is forced to exit and the entrepreneur loses all profit if caught operating informally (Galiani and Weinschelbaum, 2012).

Exit.– I assume that all the entrepreneurs face exogenous exit shocks. The time horizon is infinite, but, at any period, there is a probability χ that any entrepreneur exits at the end of the period. The exit probability is the same for all entrepreneurs. In case of exit, the entrepreneur consumes his asset holding.

Timing of incumbent entrepreneurs.– The timing is pictured in Figure 1.6. An incumbent entrepreneur starts a period with his accumulated asset, a_t, and learns right away his productivity,

income tax for a maximum period of 5 years, three years initially and renewable for an additional two years. State governments have their own taxes, and local governments have their own as well. The World Development Indicators data report a total number of 59 taxes in 2013-2014 and 48 taxes in 2015-2020 that can be paid in a total time of 430 hours in 2013-2016 or 350 hours in 2017-2020. It is clear that formality is very costly. For simplicity sake I model the formal fiscal framework with only revenue and payroll flat tax rates.

ε_t, for the current period. If he has been so far informal, he draws a fixed cost of formalization, ξ, from the uniform distribution $\mathcal{U}(0, \Xi)$, and decides whether to formalize his enterprise or not. If he decides to remain informal, he starts the next period as informal and faces the same choice. If on the contrary he decides to become formal, he incurs the formalization cost ξ drawn. From then on, he will be formal and cannot become informal again.

Then he raises capital, k_t, for the period on the financial market where he serves his assets as collateral, and hires labor. Workers are paid after production sale. Therefore, financial frictions do not distort labor allocation, except indirectly through its effect on capital.

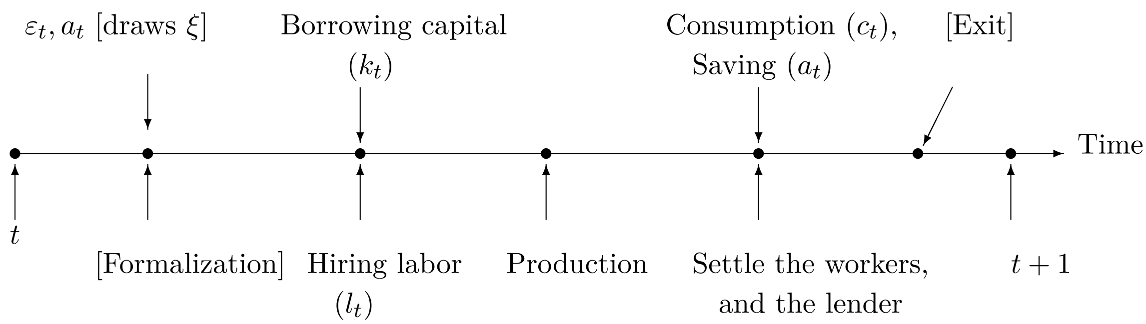

Figure 1.6: Timing

Budget constraints.– An entrepreneur earns a profit by running a formal or an informal firm. He consumes a proportion and saves the remaining, if any, by accumulating assets, a_{t+1}, for the next period. Thus, the budget constraint of an entrepreneur goes as follows.

$$(BC_j): \quad c_t + \xi \cdot \mathcal{J}_i(\varepsilon_t, a_t) + a_{t+1} = \Pi_j(\varepsilon_t, a_t) + (1 + r_t)a_t, \;\; j \in \{i, f\} \tag{1.10}$$

$\mathcal{J}_i(.)$ is a dummy function equals to 1 if the entrepreneur is newly formalizing and 0 otherwise.

Individual choices.– Entrepreneurs maximize the present discounted value of lifetime utility from consumption, subject to their budget constraints in equation (1.10). Their production and consumption/saving decisions separate in a convenient way thanks to the assumptions and the modeling approach. The value function can be rewritten conveniently in the form of a Bellman equation. Thus, the value function of a formal firm is given by:

$$V_f(\varepsilon_t, a_t) = \underset{c_t, a_{t+1}}{max} \; u(c_t) + \beta(1-\chi)\mathbb{E}\left[V_f(\varepsilon_{t+1}, a_{t+1})|\varepsilon_t\right] + \beta\chi u(a_{t+1}) \tag{1.11}$$

$$\text{s.t.} \begin{cases} c_t + a_{t+1} = \Pi_f(\varepsilon_t, a_t) + (1 + r_t)a_t \\ \Pi_f(\varepsilon_t, a_t) = \underset{k_t, l_t}{max} \left\{ (1-\tau_y)\varepsilon \left[k_t^{\alpha} l_t^{1-\alpha}\right]^{\nu} - (1+\tau_w)w_t.l_t - (r_t + \delta).k_t \text{ s.t. } k_t \leq \lambda_f.a_t \right\} \end{cases}$$

Solving the static profit maximization problem of a formal entrepreneur yields:

$$\Pi_f(\varepsilon_t, a_t) = \begin{cases} h(\varepsilon_t)(\lambda_f a_t)^{\tilde{\alpha}} - (r_t + \delta)\lambda_f a_t, & \text{if } a_t < \widetilde{K}_f(\varepsilon_t)/\lambda_f \\ h(\varepsilon_t)\widetilde{K}_f(\varepsilon_t)^{\tilde{\alpha}} - (r_t + \delta)\widetilde{K}_f(\varepsilon_t), & \text{if } a_t \geq \widetilde{K}_f(\varepsilon_t)/\lambda_f. \end{cases} \tag{1.12}$$

where $\widetilde{K}_f(\varepsilon_t) = \left[\frac{\tilde{\alpha}h(\varepsilon)}{r+\delta}\right]^{1/(1-\tilde{\alpha})}$ is the optimal capital a firm with productivity ε would raise absent the financial constraint, $h(\varepsilon) = (1-\tau_y)\varepsilon\left[1-\nu(1-\alpha)\right]\left[\frac{(1-\tau_y)\varepsilon\nu(1-\alpha)}{(1+\tau_w)w}\right]^{\nu(1-\alpha)/(1-\nu(1-\alpha))}$, and $\tilde{\alpha} = \alpha\nu/(1-\nu(1-\alpha))$. Therefore, there is a threshold asset level, $\underline{a}(\varepsilon)$, such that a firm with productivity ε and an asset below that threshold is financially constrained.

For entrants and informal entrepreneurs, the beginning of period expected value function is as follows.

$$V_i(\varepsilon_t, a_t) = \max_{\xi^*} \int_0^{\xi^*} \widetilde{V}_f(\varepsilon_t, a_t, \xi)d\mathcal{U}(\xi) + \int_{\xi^*}^{\Xi} \widetilde{V}_i(\varepsilon_t, a_t)d\mathcal{U}(\xi) \tag{1.13}$$

Therefore, the entrepreneur chooses a threshold fixed cost of formalization, ξ^*, to maximize expected value. If the realized fixed cost is lower than that threshold ($\xi < \xi^*$), he will formalize and get $\widetilde{V}_f(.)$. Otherwise, he will not formalize and will get $\widetilde{V}_i(.)$. The threshold fixed cost ξ^* is such that the firm is indifferent between formalizing and remaining informal: [6]

$$\xi^*(\varepsilon_t, a_t) = min\{\Xi, max\{0, \tilde{\xi}(\varepsilon_t, a_t)\}\} \tag{1.14}$$

where

$$\widetilde{V}_f(\varepsilon_t, a_t, \tilde{\xi}(\varepsilon_t, a_t)) = \widetilde{V}_i(\varepsilon_t, a_t) \tag{1.15}$$

In particular, if $\xi^* = 0$ the firm will not formalize whatever the fixed cost draw ξ. This can happen either with low productive entrepreneurs or with highly productive but poor entrepreneurs. The former correspond to the *survival view* of informality. They are informal not because of high formalization cost or lack of asset, but because they are too low productive. Consequently, neither lower formalization cost nor access to finance can help them formalize. The later by contrast are held back from formalization because of lack of assets. They are productive enough and would be formal, had they access to finance. Such entrepreneurs can use informality as a stepping stone. They cannot start a formal firm but can run and grow a micro or small informal firm, accumulate assets and become formal.

On the other hand, if $\xi^* = \Xi$ the firm will formalize whatever the fixed cost draw ξ. Productive and wealthy entrepreneurs enter this category.

[6] See appendix 2 for proof.

$$\widetilde{V}_f(\varepsilon_t, a_t, \xi) = \underset{c_t, a_{t+1}}{max}\ u(c_t) + \beta(1-\chi)\mathbb{E}\left[V_f(\varepsilon_{t+1}, a_{t+1})|\varepsilon_t\right] + \beta\chi u(a_{t+1}) \tag{1.16}$$

$$\text{s.t.} \begin{cases} c_t + a_{t+1} + \xi = \Pi_f(\varepsilon_t, a_t) + (1+r_t)a_t \\ \Pi_f(\varepsilon_t, a_t) = \underset{k_t, l_t}{max}\Big\{(1-\tau_y)\varepsilon\left[k_t^\alpha l_t^{1-\alpha}\right]^\nu - (1+\tau_w)w_t.l_t - (r_t+\delta).k_t \text{ s.t. } k_t \le \lambda_f.a_t\Big\} \end{cases}$$

Upon formalization, the entrepreneur incurs the additional cost of formalization, becomes formal and abides by the tax regulations.

$$\widetilde{V}_i(\varepsilon_t, a_t) = \underset{c_t, a_{t+1}}{max}\ u(c_t) + \beta(1-\chi)\mathbb{E}\left[V_i(\varepsilon_{t+1}, a_{t+1})|\varepsilon_t\right] + \beta\chi u(a_{t+1}) \tag{1.17}$$

$$\text{s.t.} \begin{cases} c_t + a_{t+1} = \Pi_i(\varepsilon_t, a_t) + (1+r_t)a_t \\ \Pi_i(\varepsilon_t, a_t) = \underset{k_t, l_t}{max}\Big\{\varepsilon_t\left[k_t^\alpha l_t^{1-\alpha}\right]^\nu - w_t l_t - (r_t+\delta)k_t - C_i(k) \text{ s.t. } k_t \le \lambda_i.a_t\Big\} \end{cases}$$

Solving the static profit maximization problem of the informal entrepreneur yields:

$$\Pi_i(\varepsilon_t, a_t) = \begin{cases} g(\varepsilon_t)(\lambda_i a_t)^{\tilde{\alpha}} - (r_t+\delta)\lambda_i a_t - C_i(\lambda_i a_t), \text{ if } a_t < \widetilde{K}_i(\varepsilon_t)/\lambda_i \\ g(\varepsilon_t)\widetilde{K}_i(\varepsilon_t)^{\tilde{\alpha}} - (r_t+\delta)\widetilde{K}_i(\varepsilon_t) - C_i(\widetilde{K}_i(\varepsilon_t)), \text{ if } a_t \ge \widetilde{K}_i(\varepsilon_t)/\lambda_f \end{cases} \tag{1.18}$$

where $g(\varepsilon) = \varepsilon\left[1-\nu(1-\alpha)\right]\left[\frac{\varepsilon\nu(1-\alpha)}{w}\right]^{\nu(1-\alpha)/(1-\nu(1-\alpha))}$, and $\widetilde{K}_i(\varepsilon)$, the optimal level of capital that a firm with the productivity ε would raise absent any financial constraint, is implicitly defined by:

$$\tilde{\alpha}g(\varepsilon)\widetilde{K}_i(\varepsilon)^{\tilde{\alpha}-1} = r + \delta + C_i'(\widetilde{K}_i(\varepsilon)) \tag{1.19}$$

The formalization decision bears a tradeoff between the costs and advantages of *becoming* a formal firm. On the one hand, the cost of becoming formal includes the opportunity cost of being informal: paying taxes and incurring the formalization fixed cost. On the other hand, the advantage of becoming formal includes avoiding the threat of fine and gaining better access to the financial market. Due to the convex cost of fine, it is almost impossible to operate a firm above a certain size informally without being caught by the authorities.

Entry.– There is a continuum pool of potential entrepreneurs of whom a constant mass $\mathcal{M} > 0$ enters the economy each period. They draw initial productivity (business idea) ε_0 from the stationary distribution $H(\varepsilon)$. The initial asset of entrepreneurs, a_0 that follows a distribution $\mathcal{A}(a)$, is not modeled. Initial productivity and asset are revealed after entry. There is a utility-denoted fixed cost of entry C_e that each new entrepreneur must pay to start business.[7] A potential entrant starts his operations if the expected value of entry exceeds the entry cost: $V_e \ge C_e$. Upon

[7] C_e can be thought of as the forgone utility of unmodeled outside options.

entry, a new entrepreneur draws a fixed cost of formalization, ξ, from the uniform distribution $\mathcal{U}(0, \Xi)$, and decides right away to be either formal or informal. If he chooses to be formal, he will pay the payroll and the revenue taxes when operating. Furthermore, he remains formal until death. If he chooses on the other hand to be informal, he will not pay taxes for the current period exercise. But he faces, like the informal incumbents, the potential cost of fine $C_i(k)$. An informal firm can still formalize later, which is the central point of this paper. Thus, the expected value of entry is given by:

$$V_e = \int \int \Big[\int_0^{\xi^*(\varepsilon_0, a_0)} \widetilde{V}_f(\varepsilon_0, a_0, \xi) d\mathcal{U}(\xi) + \int_{\xi^*(\varepsilon_0, a_0)}^{\Xi} \widetilde{V}_i(\varepsilon_0, a_0) d\mathcal{U}(\xi) \Big] d\mathcal{A}(a_0) dH(\varepsilon_0) \tag{1.20}$$

The distribution $\mathcal{A}(a)$ of new entrepreneurs asset is constructed as follows. I assume entrants draw assets from the same set A as incumbent entrepreneurs, with low assets being more probative. Let $\mathbb{P}^e(a)$ be the probability that an entrant entrepreneur draws asset level a.

$$\mathbb{P}^e(a_j) = \phi \exp(-\phi . a_j) / \sum_{i=1}^{n} \phi \exp(-\phi . a_i), \ \phi > 0 \tag{1.21}$$

The parameter ϕ governs the stickiness of the tail of the distribution $\mathcal{A}(a)$. The lower ϕ the ticker the distribution's tail and the more probable higher values of assets at entrance.

Distribution of firms.– Let $\Gamma_f^t(\varepsilon_t, a_t)$ and $\Gamma_i^t(\varepsilon_t, a_t)$ denote the *beginning-of-period t* distribution of formal and informal firms respectively and $\mathcal{M}$ denote the mass of entrant firms. Then, the motion of the distribution of formal firms is as follows.

$$\Gamma_f^{t+1}(\varepsilon_{t+1}, a_{t+1}) = (1-\chi) \Big[\int \Gamma_f^t(\varepsilon_t, a_t) \mathcal{J}_f(\varepsilon_t, a_t, a_{t+1}) dH(\varepsilon_{t+1} \,|\, \varepsilon_t) + \int \Gamma_i^t(\varepsilon_t, a_t) \mathcal{J}_i(\varepsilon_t, a_t, a_{t+1}) dH(\varepsilon_{t+1} \,|\, \varepsilon_t) \Big] + \mathcal{M} \int \mathcal{E}_f(\varepsilon_{t+1}, a_{t+1}) dH(\varepsilon_{t+1}) \tag{1.22}$$

The first term represents incumbent formal firms that do not exit, the second term the incumbent formerly informal firms that just formalized, and the third term stands for new firms that enter as formal ones. $\mathcal{J}_f(\varepsilon_t, a_t, a_{t+1})$ is an indicator function equal to 1 if a formal entrepreneur with states (ε_t, a_t) saves a_{t+1}, $\mathcal{J}_i(\varepsilon_t, a_t, a_{t+1})$ is an indicator function equal to 1 if an informal entrepreneur with states (ε_t, a_t) formalizes and saves a_{t+1}, and $\mathcal{E}_f(\varepsilon_{t+1}, a_{t+1})$ is an indicator function equal to 1 if a new entrepreneur with states $(\varepsilon_{t+1}, a_{t+1})$ formalizes.

Similarly, the motion of the distribution of informal firms is given by:

$$\Gamma_i^{t+1}(\varepsilon_{t+1}, a_{t+1}) = (1-\chi) \int \Gamma_i^t(\varepsilon_t, a_t) \left[1 - \mathcal{J}_i(\varepsilon_t, a_t, a_{t+1})\right] dH(\varepsilon_{t+1} \,|\, \varepsilon_t) + \mathcal{M} \int \left[1 - \mathcal{E}_f(\varepsilon_{t+1}, a_{t+1})\right] dH(\varepsilon_{t+1}) \tag{1.23}$$

The first term represents incumbent informal firms that neither exit nor formalize, and the second term new firms that enter as informal ones.

With $\chi > 0$, Γ_i and Γ_f have unique invariant distributions and will be constant in steady state. Additionally, the distributions are linear in the mass of entrants $\mathcal{M}$.

3 .2 The corporate firms sector

Sub-Saharan African economies are composed of a large proportion of small firms and a minority of large firms. Using different sources of data, I find out that in Nigeria for example firms with 200 employees or more represent only 0.0537% among all non-agricultural firms but account for 16% of their employment. Meanwhile, the proportion of firms of 1 or 2 employees is more than 83%. Following Galindo da Fonseca (2022) and Cagetti and De Nardi (2006), I model the corporate sector with the same DRS production function as the entrepreneurial sector.

$$Y_c = \bar{\varepsilon}_c \left(K_c^{\alpha} L_c^{1-\alpha} \right)^{\nu} \tag{1.24}$$

where $\bar{\varepsilon}_c$ is a constant productivity of the representative coporate firm. The corporate firm is formal, therefore it pays the revenue and the payroll taxes, but does not face a financial constraint. So its policy functions are given by $K_c^* = \widetilde{K}_f(\bar{\varepsilon})$ and $L_c^* = \left[\frac{(1-\alpha)\nu(1-\tau_y)\bar{\varepsilon}_c}{(1+\tau_w)w}\right]^{\frac{1}{1-\nu(1-\alpha)}}$. $\widetilde{K}(\bar{\varepsilon}_c)^{\frac{\alpha\nu}{1-\nu(1-\alpha)}}$.

3 .3 The household

There is a representative hand-to-mouth household that supplies labor service to firms for a wage w_t per unit labor and consumes the labor income. It derives utility from consumption and suffers a disutility from working according to the function $u(c_t, l_t) = \log(c_t) - \Upsilon.l_t$. The budget constraint of the household is $c_t = w_t \cdot l_t$.

3 .4 The government

There is a government that collects taxes from the formal enterprises and enforces informal firms. The government uses the proceeds to finance unmodeled needs, G_t. The tax revenue of the government is given by:

$$R_t = \tau_y \int y(\varepsilon_t, k_f^*(\varepsilon_t, a_t)) d\Gamma_f^t(\varepsilon_t, a_t) \; + \; \tau_w \cdot w_t \int n_f^*(\varepsilon_t, a_t) d\Gamma_f^t(\varepsilon_t, a_t) + \tau_y Y_c^* + \tau_w L_c^* \tag{1.25}$$

3 .5 Competitive Equilibrium

A stationary recursive competitive equilibrium consists of beginning-of-period value functions $V_f(\varepsilon, a)$, and $V_i(\varepsilon, a)$, policy functions for labor, capital, consumption and saving, cut-off values $\xi^*(\varepsilon, a)$, wage w, and interest rate r, distributions Γ_f and Γ_i, measure of entrants $\mathcal{M}$, government revenue R and government expenses G such that:

1. The household optimizes: $l^s = \dfrac{1}{\Upsilon}$.

2. V_f, V_i, V_e and the associated policy functions solve the respective incumbent and entrant firm's problem.

3. The government budget balances: $G = R$.

4. The distributions over incumbent firms are stationary: $\Gamma_j^{t+1} = \Gamma_j^t$, $j \in \{i, f\}$.

5. The labor market clears:

$$L = l^s = l^d = \int l_f^d(\varepsilon, a) d\Gamma_f(\varepsilon, a) \; + \; \int l_i^d(\varepsilon, a) d\Gamma_i(\varepsilon, a) + L_c^*$$

6. The capital market clears:

$$K = \sum_{j \in \{i,f\}} \int k(\varepsilon, a) d\Gamma_j(\varepsilon, a) \; + \; K_c^* = \sum_{j \in \{i,f\}} \int a d\Gamma_j(\varepsilon, a)$$

4 Results

4 .1 Discussion: the mechanisms of the model

Forces that govern formalization decision.– Formalization decision in the model involves a tradeoff between the cost of informality (potential fine) and the cost of formality (taxes). In addition, formalization gives increased access to external finance. Tax rates, easiness of getting external finance captured by λ_i and λ_f, and informality enforcement are common for all firms. They jointly determine the institutional environment that shapes entrepreneurship along with the characteristics of entrepreneurs. Given the institutional parameters, formalization is probabilistic and depends on productivity and asset of entrepreneurs. Figure 1.7 shows the probability of formalization with respect to the two dimensions, for chosen parameters and prices. It shows that unproductive entrepreneurs never formalize, no matter how rich they are. On the contrary, productive and wealthy entrepreneurs surely formalize. In between are productive but poor entrepreneurs. Productivity-wise they have the capacity to run firms formally. But their low level of assets constrains the capital of their firm and makes formality too costly compared to potential fine. Therefore, informal entrepreneurship can serve as a *stepping stone* while the entrepreneur accumulates assets to formalize.

Figure 1.8 shows a firm that starts out as informal and transition later to formal. With a very low asset at start, the high-productivity fictive entrepreneur operates informally for six years while accumulating assets. Eventually, he/she formalizes and continues growing for over 40 years before reaching a long run optimal size. But, will every high-productivity entrepreneur that starts informally transition to become formal ?

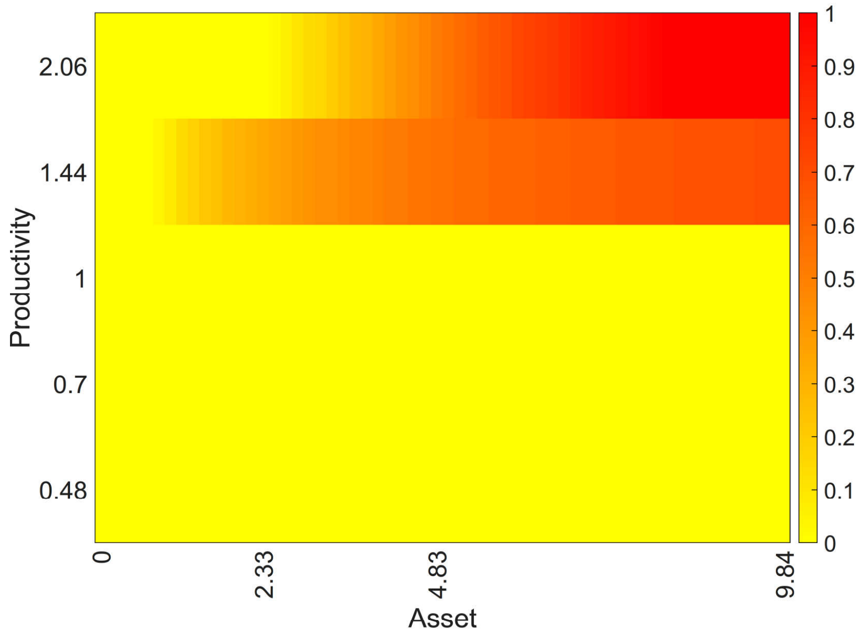

Figure 1.7: Formalization probability. Figure shows a heatmap of a firm's probability of formalization as a function of productivity and asset. Yellow area corresponds to low probability and red area to high probability.

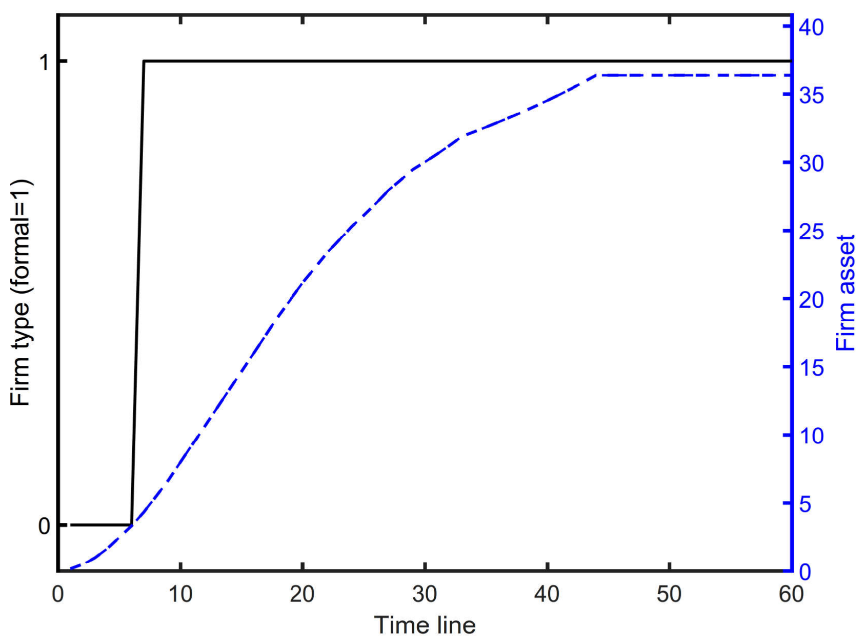

Figure 1.8: Transition form informality to formality. Figure shows a firm transitioning from informality to formality. Left y-axis represents the type where 1 means formal and 0 means informal. Right y-axis represents the asset level of the firm. X-axis shows time flow.

Importance of initial assets.– It turns out that the initial asset can be critical for the formalization decision. Figure 1.9 plots the same entrepreneur with different initial assets. On the left graph where initial asset is low, he/she does not formalize but consumes asset to the level that is just enough to keep an informal firm under the radar. On the right graph, the initial asset is a bit higher. Interestingly the entrepreneur chooses to formalize and grow business for many years.

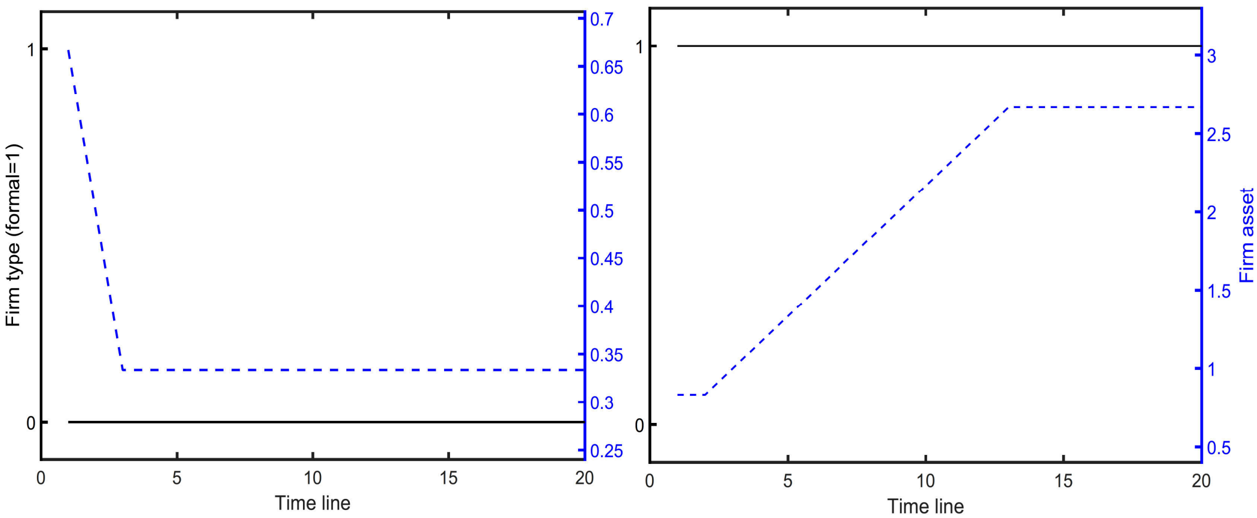

Figure 1.9: Initial assets matter for formalization. Figure shows informality choice and asset accumulation of entrepreneur depending on the initial assets. Productivity is the same. In the left figure entrepreneur starts with low assets while he/she starts with higher asset in the right figure. Left y-axis represents the type where 1 means formal and 0 means informal. Right y-axis represents the assets level of the firm. X-axis shows time flow.

The role of financial frictions.– In order to gauge the role of financial constraints, I simulate the firms in Figures 1.8 and 1.9 in an environment that is similar in every way, except there is no financial constraints. The result is shown in Figure 1.10. When there is no financial constraints, entrepreneurs do not hold assets at the detriment of consumption. However, they formalize their business. In the left-hand figure, formalization is sped up compared to what is seen with financial constraints. In the middle figure, the firm formalizes after four years while it does not formalize in presence of financial constraints. The entrepreneur in the right-hand figure formalizes anyway but is better off with higher consumption in absence of financial constraints.

The transitions in Figures 1.8 through 1.10 are driven by asset accumulation dynamics. Another channel in the model through which a firm can transition from informality to formality is productivity shock. That would correspond to a bottom-up jump in Figure 1.7. A low-productivity entrepreneur with some good level of assets becomes productive and formalizes.

4 .2 Calibration

To solve the model numerically, I use value function iteration with interpolation. In the baseline model, the interest rate is set to 4%, a value commonly used in the literature. Then I find equilibrium wage that clears the labor market by bisection, while the mass of entrants $\mathcal{M}$ is determined so to clear the capital market. The entry cost C_e is equal to the expected value of new entrants V_e. In the counterfactual, interest rate is determined by bisections to clear the capital market, the

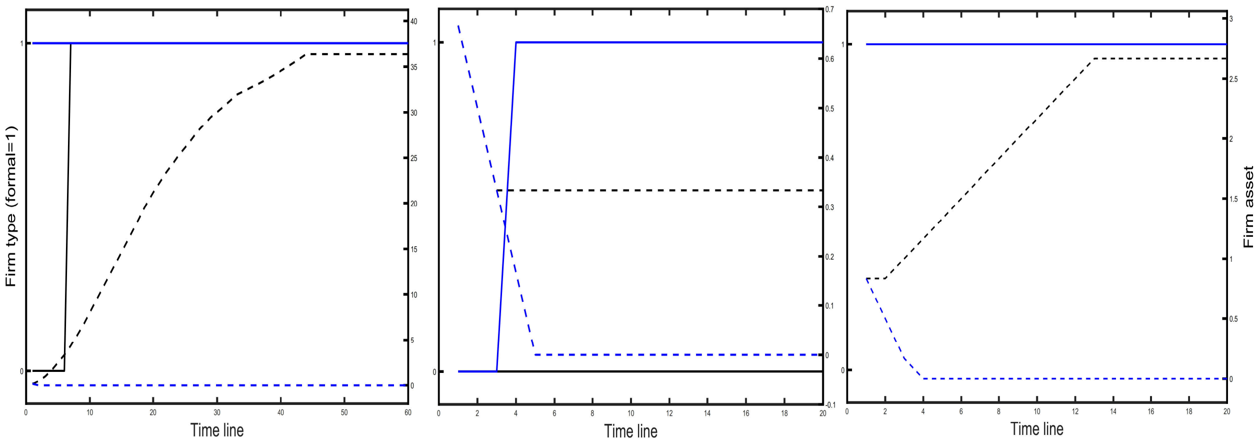

Figure 1.10: The role of financial constraints. Figure compares informality choice and asset accumulation of entrepreneurs with and without financial constraints. Plain lines represent the type of firm (formal/informal) while dash-lines represent their assets. Black color represents the choice in presence of financial constraints while blue color represents the choice when financial constraints are removed. Right and middle figures correspond to same productivity with different initial assets, while the left figure corresponds to higher productivity. Left y-axis represents the type where 1 means formal and 0 means informal. Right y-axis represents the asset level of the firm. X-axis shows time flow.

mass of clears the labor market, while the wage is determined by bisections to ensure that the entry condition holds.

Some parameters are preset, while others are calibrated to match data moments. The parameters set outside the model are shown in Table 1.7. I set λ_i equal 1 following D'Erasmo and Moscoso Boedo (2012) and Pratap and Quintin (2008). Ranasinghe and Restuccia (2018) calibrated a similar framework to a U.S economy frictionless counterfactual to find the discount factor. I follow them to set β to 0.93 and γ to 1.5. Following Buera and Shin (2013) and Restuccia and Rogerson (2008), I set the span-of-control parameter ν to 0.85, and split it into labor and capital shares with α equal 1/3. I use the standard value of 10% for the depreciation rate δ, while the exit probability χ is set equal 6.67%, corresponding to the inverse of average age of firms in Nigeria (15 years). The labor disutility Υ is set equal 0.86 as in Adom and Schott (2022). In addition, tax rates τ_y and τ_w are set respectively to 30% and 14.5% based on the Doing Business report (2020) for Nigeria.

The eight remaining parameters $\Theta = \{\rho_\varepsilon, \sigma_\varepsilon, \lambda_f, \theta, \psi, \Xi, \phi, \bar{\varepsilon}_c\}$ are calibrated to Nigerian economy by matching eight data moments that are informative about the joint distributions of firms, employment, and firm types. The parameters were determined by minimizing the sum of the absolute difference between data and model moments. The calibrated parameter values are shown in Table 1.8, as well as a comparison between data and model moments. The parameters are jointly determined, yet I briefly describe the intuition that guides the identification and the choice of data moments. It is important to inform here that the calibration is constrained by data limitations. In particular, I do not have access to the raw firm-level data of the entire (non-agricultural) economy. Instead, the WBES provide firm-level information about the formal economy while the Small and Medium Enterprises Development Agency of Nigeria (SMEDAN), joint with the National Bureau

Table 1.7: External calibration

Parameter	Description	Value	Source(s)
β	Discount factor (entrepreneurs)	0.9300	Ranasinghe & Restuccia (2018)
γ	RRA - (entrepreneurs)	1.5000	Ranasinghe & Restuccia (2018)
α	Technology: capital share	0.3333	Buera & Shin (2013)
ν	Technology: return to scale	0.8500	Buera & Shin (2013)
λ_i	Financial constraint: informal firms	1.0000	Data and literature
τ_y	Income tax	0.3000	Doing Business 2020
τ_w	Payroll tax	0.1450	Doing Business 2020
δ	Depreciation rate of capital	0.1000	Literature
χ	Death probability	0.0667	Data: 1/Avg. age of firms
Υ	Labor disutility of HH	0.8600	Adom & Schott (2022)
$\mathcal{M}$	Mass of new entrants	0.0032	Capital market clearing

of Statistics of Nigeria report on small and medium enterprises (fewer than 200 employees) provide summary statistics about said enterprises. One limitation for example is that firm size distribution is constrained to the distributions defined in the reports.

The productivity parameters ρ_ε and σ_ε shape the firm size distribution. Therefore, I use them to match the proportion of nano and micro firms (employment less than 10) on the one hand and the proportion of small firms (10 to 49 employees) on the other hand. As λ_f captures the ability of formal firms to borrow capital, it is used to match the proportion of external financing among those firms. ϕ governs the initial asset draw of new entrepreneurs. Therefore, it affects the proportion of informal firms while Ξ determines the proportion of switchers among formal firms. θ captures the probability for an informal firm to be detected by the government and ψ captures the cost of fine once an informal firm is detected. Both determine how small or big a firm can be under the radar. I use them to target the employment share of informal firms and the proportion of nano and micro among formal firms, respectively. Finally, $\bar{\varepsilon}_c$ is calibrated targeting the employment share of non-large firms, i.e, MSMEs.

Table 1.8: Internal calibration

Parameter	Description	Value	Target moment	Data	Model
ρ_ε	Productivity persistence	0.9784	Prop. of nano and micro firms	0.9800	0.9090
σ_ε	Productivity st. dev.	0.0636	Prop. of small firms	0.0156	0.0468
λ_f	Fin. const.: formal firms	1.1008	Prop. of ext. financing of FF	0.0700	0.0872
ϕ	Initial asset draw parameter.	0.0461	Prop. of informal firm	0.9400	0.9600
Ξ	Form. fixed cost upper bound	0.6085	Prop. of switchers in FF	0.3100	0.2660
ψ	Informality cost: shifter	0.9616	Employment share of IF	0.8000	0.7639
θ	Informality enforcement prob.	0.2150	prop. of nano & micro in FF	0.4869	0.5170
$\bar{\varepsilon}_c$	Labor demand of corporate firms	0.6007	Employment share of MSMEs	0.8402	0.8643

Notes. Table shows data moments match by the model. FF stands for "formal firms" and IF for "informal firms".

Table 1.8 shows that the model matches the data moments well, both unconditionally and conditional on firms formality type. In particular, the proportions of informal firms and the proportion of switchers in formal firms are relatively well replicated. In addition, the model is successful in replicating the preponderance of nano and micro firms seen in the data as well as the proportion of external financing by formal firms.

The model is also successful in replicating some untargeted data moments as shown in Table 1.9. In particular, the model replicates overall well the size distribution of firms both unconditionally and conditionally. Nevertheless, informal firms in the model are bigger than in the data as the average employment of informal firms is greater in the model than in the data. Finally, although the model overshoots the production share of informal firms, the value is still in the range of the estimates reported in the literature.

Table 1.9: Untargeted moments match

Moment	Data	Model
All firms: proportion of nano (1-2)	0.8326	0.6757
All firms: proportion of micro (3-9)	0.1500	0.2333
All firms: proportion of small (10-49)	0.0156	0.0468
All firms: proportion of medium (50-199)	0.0013	0.0442
All firms: proportion of large (200 plus)	0.0005	0.0000
Formal firms: proportion of nano (1-2)	0.0091	0.0413
Formal firms: proportion of micro (3-9)	0.4778	0.4757
Formal firms: proportion of small (10-49)	0.4576	0.4074
Formal firms: proportion of medium (50-199)	0.0476	0.0756
Formal firms: proportion of large (200 plus)	0.0078	0.0000
Informal firms: proportion of GDP	0.4800	0.6642
Informal firms: Avg. size	1.6000	5.8416
Formal firms: Avg. size	18.4000	18.4000

4 .3 Counterfactual analyses

Some papers have assessed the effectiveness of formalization policies. de Andrade et al. (2016) conducted a field experiment in the city of Belo Horizonte (Brazil) and found that providing formalization information or removing formalization costs did not lead informal firms to formalize. Overall, reforms aimed at making it easier and cheaper for firms to formalize result in only a modest short-lived increase in the number of formal firms, if there is any increase at all (Galiani, Meléndez, and Ahumada, 2017; de Andrade et al., 2016; Bruhn and McKenzie, 2014; de Mel et al., 2013; Jaramillo, 2013). Rather, increased enforcement of rules can increase formality (de Andrade et al., 2016). Although there is a fiscal benefit of doing this with larger informal firms, it is unclear whether there is a public rationale for attempting to formalize subsistence enterprises (Bruhn and McKenzie, 2014). However, few studies have been conducted in Africa. Campos, Goldstein, and McKenzie (2018) conducted a randomized experiment in Malawi and found an incredibly high demand for obtaining a formal status that is separated from tax obligations, and very low take-up of tax registration. While information alone did not trigger formalization in Benin, when additionally firms were visited in person and the benefits of formalization – like government training programs, support to open bank accounts, and tax mediation services – were explained, the formalization rate is boosted by up to 16.3% (Benhassine, McKenzie, Pouliquen, and Santini, 2018).

The model of this paper can now be used to assess the effects of many informality-related policies. Doing that contributes to the literature in three ways. First, the model offers a virtual laboratory to assess various policies while taking into account the stepping stone margin that has been ignored in the literature so far. Second, it extends the analysis to SSA that has received a very limited attention in the literature despite a high rate of informality. Third, in addition to policies that aim at reducing formality costs I assess other policies that have received no or little attention in the literature. Financial constraints are regularly reported as an impediment to business growth and hence to formalization. In Nigeria for example the government has put in place a policy aiming to lend money to young entrepreneurs if only they are willing to formalize their business.[8] I assess such a policy by removing financial constraints for both formal and informal firms jointly and alternatively. I also assess the potential impact of an improvement of entrepreneurs productivity through, for example, entrepreneurship training. Finally, I assess the effectiveness of enforcement to reduce informality. The structure of enforcement in the model allows me to distinguish between the effects of increasing detection of informal firms and increasing the cost of fine.

4 .3.1 Effect of lowering taxes

Taxes are certainly the most important cost of formality. Unlike the fixed cost of formalization, paying taxes is recurrent and the entrepreneur commits to it in the long run once formal. I simulate alternatively two policies that lower revenue and payroll taxes by half, everything else equal. The result is reported in Table 1.10.

Revenue tax.– Lowering revenue tax on formal firms reduces informality rate by 39 percentage points. Not only does the proportion of formal firms increase, but the proportion of switchers among formal firms also increases by 12 percentage points. The overall effect is a reallocation of the economy to the formal sector: the employment share of informal firms decreases by 70 percentage points and the GDP share of informal firms by 62 percentage points. As firms become bigger, the proportion of nano and micro enterprises in the economy drops by 14 percentage points, and aggregate production increases by 33 percent. The extensive margin effect (more formal firms paying taxes) exceeds the intensive margin effect (each formal firm pays less tax) on the government tax revenue, which more than doubles.

Payroll tax.– Lowering the payroll tax by half decreases informality rate by 10 percentage points and informal firms share of employment by 37 percentage points. On the other hand, it increases

[8] See Nigerian Youth Employment Action Plan

Table 1.10: Lowering taxes

Moments	Baseline	Lower taxes	
		Revenue tax	Payroll tax
Firms: prop of informal	96.00	-38.73	-10.25
Firms: switchers to formals prop.	26.60	+12.33	+11.38
Informal firms: proportion of employment	76.39	-69.98	-37.03
Informal firms: proportion of GDP	66.42	-61.58	-36.67
Firms: Proportion of nano and micro	90.90	-13.60	+0.12
Employment share of MSME	86.43	-1.39	-0.90
Government tax revenue (% of GDP)	11.76	+8.32	+11.20
Aggregate production	1.00	1.33	1.18
Aggregate employment	1.00	1.00	1.00

Notes. Lines "Aggregate production" and "Aggregate employment" are normalized to 1 in the baseline. For other lines, proportions are reported in the baseline while percentage point variations from the baseline are reported in the counterfactuals.

the government tax revenue by 145% and aggregate production by 18 %. It also increases the proportion of switchers among formal firms by 11 percentage points.

4 .3.2 Effect of lowering formalization cost

Formalization cost captures regulation hurdles to formalize a business. In Table 1.11, I simulate a policy that lowers formalization cost by 10% from the baseline. The results show that the policy is ineffective to induce significant change in informality rate, but it increases the proportion of switchers in formal firms by 56 percentage points. It induces however a lower aggregate production due to general equilibrium effect of higher interest rate.

Table 1.11: Lowering formalization cost

Moments	Baseline	Lower formalization cost
Firms: prop of informal	96.00	-0.27
Firms: switchers to formals prop.	26.60	+55.92
Informal firms: proportion of employment	76.39	-11.66
Informal firms: proportion of GDP	66.42	-13.54
Firms: Proportion of nano and micro	90.90	+0.87
Employment share of MSME	86.43	-2.12
Government tax revenue(% of GDP)	11.76	+4.74
Aggregate production	1.00	0.94
Aggregate employment	1.00	1.00

Notes. Lines "Aggregate production" and "Aggregate employment" are normalized to 1 in the baseline. For other lines, proportions are reported in the baseline while percentage point variations from the baseline are reported in the counterfactual.

4 .3.3 Effect of improving access to external finance

Can better access to external finance help foster firm formalization? Table 1.12 reports the result of removing financial constraints first for all firm, and then alternatively for formal firms and for informal firms. Removing financial constraints for formal firms can reduce informality rate by 6 percentage points while removing them for informal firms reduces informality rate only by 3 percentage points. The policy generates a substantive reallocation of the economy to the formal sector with a very large effect on the government tax revenue. But it also induces more small firms in the economy. Interestingly, it significantly reduces the proportion of switchers in formal firms as more firms that could be formal formalize from start. That shows that financial constraints play an important role in the process off transition from informality to formality.

Table 1.12: Improving access to external finance

Moments	Baseline	No financial friction for ...		
		All	Formal firms	Informal firms
Firms: prop of informal	96.00	-5.34	-5.82	-3.05
Firms: switchers to formals prop.	26.60	-18.74	-17.16	-23.93
Informal firms: proportion of employment	76.39	-44.27	-44.71	-4.92
Informal firms: proportion of GDP	66.42	-43.98	-44.33	-5.92
Firms: Proportion of nano and micro	90.90	+0.54	+0.52	-1.44
Employment share of MSME	86.43	+12.48	+11.4	+3.47
Government tax revenue(% of GDP)	11.76	+15.40	+15.53	+2.07
Aggregate production	1.00	2.06	1.64	1.38
Aggregate employment	1.00	1.00	1.00	1.00

Notes. Lines "Aggregate production" and "Aggregate employment" are normalized to 1 in the baseline. For other lines, proportions are reported in the baseline while percentage point variations from the baseline are reported in the counterfactuals.

4 .3.4 Effect of improving entrepreneurs productivity

Are most firms informal because the entrepreneurs are not productive? In Table 1.13, I simulate a policy that improves the productivity of entrepreneurs by multiplying the average of the productivity process ε by two. As expected, improving productivity does lower informality incidence. The percentage points change from the baseline model is -18. Interestingly, the proportion of switcher among formal firms drops because more firms formalize from start. The overall effect is a very large increase in aggregate production and the government revenue.

4 .3.5 Effect of increasing enforcement

Enforcement generates substantive decline in informality along with government tax revenue increase. While detection and fine are complementary, informality is less sensitive to the first than to the last. Thus, multiplying the fine cost by two reduces informality rate by 19 percentage point with

Table 1.13: Improving entrepreneurs productivity

Moments	Baseline	Double productivity
Firms: prop of informal	96.00	-18.28
Firms: switchers to formals prop.	26.60	-4.71
Informal firms: proportion of employment	76.39	-18.46
Informal firms: proportion of GDP	66.42	-20.71
Firms: Proportion of nano and micro	90.90	-19.91
Employment share of MSME	86.43	+12.98
Government tax revenue(% of GDP)	11.76	+7.25
Aggregate production	1.00	3.30
Aggregate employment	1.00	1.00

Notes. Lines "Aggregate production" and "Aggregate employment" are normalized to 1 in the baseline. For other lines, proportions are reported in the baseline while percentage point variations from the baseline are reported in the counterfactual.

significant reallocation of resources from informality to the formal economy (Tabe 1.14). Increasing detection (by doubling θ) while holding the penalty fixed is less effective, reducing informality rate by 12 percentage points.

Table 1.14: Increasing enforcement

Moments	Baseline	Increased enforcement	
		Detection	Fine cost
Firms: prop of informal	96.00	-11.93	-18.88
Firms: switchers to formals prop.	26.60	+1.29	-7.03
Informal firms: proportion of employment	76.39	-25.45	-55.88
Informal firms: proportion of GDP	66.42	-27.59	-52.79
Firms: Proportion of nano and micro	90.90	-1.25	-1.16
Employment share of MSME	86.43	-0.37	-1.92
Government tax revenue (% of GDP)	11.76	+9.66	+18.49
Aggregate production	1.00	1.09	1.23
Aggregate employment	1.00	1.00	1.00

Notes. Lines "Aggregate production" and "Aggregate employment" are normalized to 1 in the baseline. For other lines, proportions are reported in the baseline while percentage point variations from the baseline are reported in the counterfactuals.

4 .3.6 Informality and aggregate TFP

Informality is thought to be closely linked to aggregate productivity since informal firms generally tend to be small and unproductive. The model of this paper can be used to assess the quantitative importance of this linkage. Following D'Erasmo and Moscoso Boedo (2012), I compute aggregate total factor productivity (TFP) with the formula in equation (1.26).

$$TFP = \frac{\sum_{j \in \{i,f\}} \int y_j(\varepsilon, a) d\Gamma_j(\varepsilon, a) + Y_c}{\left[K^\alpha L^{(1-\alpha)}\right]^\nu} \tag{1.26}$$

The result is reported in Table 1.15 along with a summary of the results presented in Tables 1.10 through 1.14. Overall, all experimented policies reduce informality rate and also increase aggregate TFP. The different policies are not comparable because they are carried out by altering parameters of different natures. But Aggregate TFP increase is particularly large when entrepreneurs productivity is enhanced and when financial frictions are removed.

Table 1.15: Informality and aggregate TFP

	% Δ of TFP	pp Δ of informality rate	% Δ of production	pp Δ of gvt tax revenue (in % of GDP)
Lower revenue tax	+8.07	-38.73	+32.67	+8.32
Lower payroll tax	+5.45	-10.25	+17.61	+11.20
Lower formalization cost	-3.77	-0.27	-5.62	+4.74
No financial constraint				
All	+38.26	-5.34	+106.36	+15.40
Only formal firms	+24.82	-5.82	+64.39	+15.53
Only informal firms	+13.16	-3.05	+38.19	+2.07
Higher productivity	+130.75	-18.28	+230.22	+7.25
Increased detection	+1.94	-11.93	+9.28	+9.66
Increased fine cost	+6.84	-18.88	+22.73	+18.49

Notes. Table summarizes the effect of different simulated policies on informality rate, aggregate TFP and production, and government tax revenue as proportion of GDP. The second and last columns reports percentage point variations from the baseline model while remaining columns report percentage variations from that baseline.

In sum, my framework does not corroborate the existence of a tradeoff between informality and aggregate production as previously argued in the literature (Ulyssea, 2018). Neither is strict enforcement the only way to reduce informality or even the best to increase government tax revenue while reducing informality. Increasing entrepreneurs productivity is more potent and can possibly be achieved through education and entrepreneurship training.

5 Conclusion

In this paper, I showed that the proportion of firms that started as informal and become formal later is higher in Sub-Saharan Africa than previously reported in the literature for other countries. Empirical analyses show that this is associated with financial constraints and fiscal administrative procedures hurdles. I then built a quantitative general equilibrium model of heterogeneous firms that accounts for transition from informality to formality. After calibrating the model to the Nigerian economy, the results show that transition from informality to formality is more responsive to policies than overall informality. According to the results, there needs not be a trade-off between informality and aggregate production. Neither is strict enforcement the only way to reduce informality or even the best to increase government tax revenue while reducing informality. Increasing entrepreneurs' productivity is more potent and can possibly be achieved through education and entrepreneurship training.

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Article 2

Time Delays at the Border: Macroeconomic Consequences for Sub-Saharan African Economies* †

Idossou Marius ADOM‡

Abstract.– Time delays to clear imported inputs are longer in Sub-Saharan African countries than in advanced economies. In some countries, the average clearance delay exceeds a month while it is about five days or less in Germany, Greece, Ireland or Thailand. This paper argues that these delays generate input disruptions in Sub-Saharan Africa and quantifies their effects. To this end I develop a dynamic general equilibrium model where firms' foreign inputs are subject to random time delays. After calibrating the model to the data, I simulate a scenario where the average border delay is reduced to one week or less. I found that firms place higher foreign input orders in the baseline model to self-insure against *ex-ante risk* of input disruptions. However, aggregate foreign input is lower in steady state due to *ex-post realizations* of the delays. In the counterfactual, eliminating the delays induces aggregate output to increase by up to 10% and employment by up to 5.8%. These gains are driven mainly by a substantial increase of foreign inputs use.

Key words: Border delays, customs clearance, foreign inputs, disruption, Sub-Saharan Africa.

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"As a manufacturer, one of our biggest headaches is with the supply chain. We have a situation where we have to order materials three months or six months ahead because of clearing delays."

– Jude Abalaka, managing director of Tranos Contracting Limited, Nigeria.[2]

1 Introduction

Firms in most Sub-Saharan African countries import a significant proportion of their inputs. But due to red tape and lack of adequate infrastructure, the customs clearance process is longer than in developed countries. These delays cause input disruptions and affect adversely the ability of firms to produce. This paper studies the macroeconomic effects of border delays on investment, employment, and production. To this end I develop a dynamic general equilibrium model where firms' foreign inputs are subject to random delays. After calibration, I simulate the model for a scenario where the average delay is brought down to a week or less. The average border delay of seven days or less observed in developed countries such as Germany or Ireland motivates this scenario. The results show that firms place higher investment orders in the baseline model compared to the frictionless one to self-insure against *ex-ante risk* of input disruptions. However, aggregate foreign input is lower in steady state due to *ex-post realizations* of input disruptions. Thus, reducing border delays to one week or less in the counterfactual increases aggregate production by up to 10.2% and employment by up to 5.8%.

It has been shown that delivery delays affect negatively trade and thereby economic development (Hummels and Schaur, 2013; Hoffman, Grater, Schaap, Maree, and Bhero, 2016). I argue in this paper that border delays also affect firms' production directly by causing input disruptions. I use data from the World Bank Enterprise Surveys to compute the average time imported inputs remain in customs in Sub-Saharan African countries and in some advanced economies including Germany, Ireland, Greece and Thailand.[3] Figure 2.1 shows how the result varies across Sub-Saharan Africa. While the average border delay is less than seven days in Germany, Ireland, Greece, or Thailand, it exceeds three weeks in most Sub-Saharan African countries.[4] In many instances, firms reported having to wait more than a month. Sometimes, the process lasts longer than three months. In Mali for example, customs clearance takes 31.5 days on average, with a maximum of 180 days.

[2] https://www.thebusinessyear.com/nigeria-2018/jude-abalaka-managing-director-tranos/vip-interview

[3] Border delay includes all clearances required from the moment the goods arrived at their point of entry until the moment they satisfy the requirements of the clearance procedures at the customs office and can be claimed. It does not include time spent on transportation to reach the point of entry, but it includes waiting time to enter customs.

[4] Few Sub-Saharan African countries have an average border delay of one week or less: Botswana, Djibouti, Eswatini (the official name of Eswatini was formerly Swaziland), Lesotho, Namibia, Somalia, and Sudan.

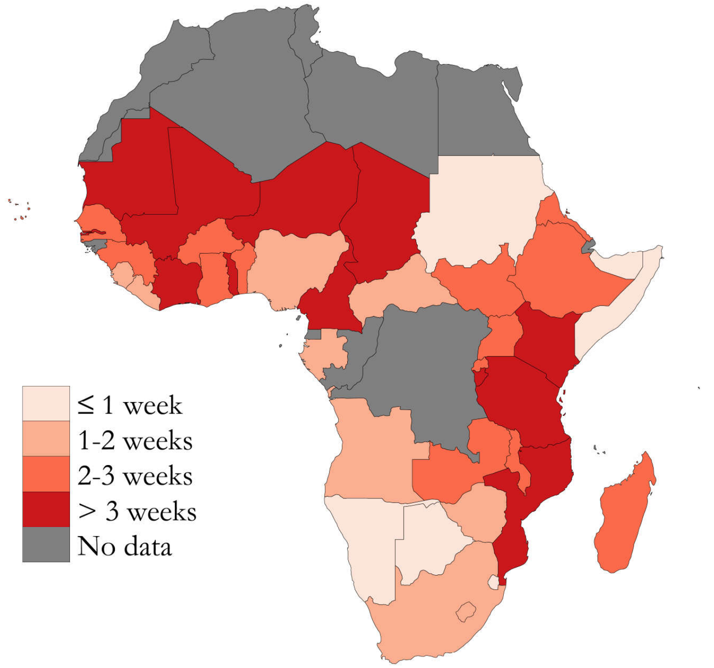

Figure 2.1: Average border delays (in days) in Sub-Saharan Africa. Source: WBES data and author's calculations. *Notes:* The time imported inputs remain in customs includes all clearances required from the moment the goods arrived at their point of entry until the moment they meet customs requirements and can be picked up. It does not include time spent on transportation to reach the point of entry but it includes waiting time to enter customs.

Border delays are not only a source of additional costs for firms, but also a source of uncertainty as the exact delay is not known in advance. The data show indeed great variability of border delays within and across countries (see section 2 .1). As shown in Bloom (2009), uncertainty is a major concern for firms' investment, employment, and growth. Many other studies identified delays that result from international movement of goods as a major problem that enterprises are facing in Sub-Saharan Africa (SSA hereafter).[5]

The paper is related to three strands of the literature. First, it is related to the literature on *time to build* where a new investment takes some time before it becomes productive (Kydland and Prescott, 1982; Altug, 1989; Rouwenhorst, 1991; Chang, 1995; Christiano and Todd, 1996; Casares, 2006). Conceptually the time delay I consider in this paper is different from the *time to build* by its randomness. The number of periods it takes an investment project to complete in the *time to build* models is determined, fixed and known; therefore it is not a direct source of uncertainty.[6] In this paper, time delay does not arise from the *time to build* per see, but from border administration inefficiency, which is beyond firms' control. Meier (2020) studies the effects of the capital market search-and-match delay on the business cycle in the U.S. while Carreras-Valle (2022) builds a model of delivery delay where a proportion of investment order is delivered each period. In the latter every investment order is delivered within two periods. In my paper, time delay is exogenous and modeled

[5]e.g. OECD (2005); The World Economic Forum (2012); Moïsé and Sorescu (2013); UNECA (2013); Valensisi and Lisinge (2013).

[6]When firms have varying stochastic productivity, even the constant fixed *time to build* leads to increasing uncertainty because of imperfect foresight (See Meier (2020)).

as a stochastic binary process each period so that an investment order may remain nondelivered for several periods.

Second, my paper is related to the literature on the effects of time delays (including transportation delays) on international trade (Hoffman et al., 2016; Hummels and Schaur, 2013; Plane, 2021). This literature does not consider the *direct* effects of the delays on firms, but infers their *indirect* effects through trade. By contrast, my paper analyzes the effects of delays on the production process while abstracting from trade.

Third, this paper is related to the literature on *investment specific technology shocks* because it models the delay process as an exogenous shock to new foreign input investments. Papers in this literature emphasize the role of investment specific shocks in explaining business cycle and growth in the U.S. (Ma, 2018; Chen and Wemy, 2015; Ben Zeev and Khan, 2015; Justiniano, Primiceri, and Tambalotti, 2010; Greenwood, Hercowitz, and Krusell, 2000, 1997), and in developing economies (Dogan, 2019; Araùjo, 2012). However, there is no clear definition or consensus on what an investment specific technology shock is, or even how it comes about (Guerrieri, Henderson, and Kim, 2010). This paper provides a solid and clear motivation for the source of such a shock.

Finally, it is worth highlighting that the paper is policy relevant as it quantifies the gain from achieving better clearance processes - that is to catch up with the world's best practices - in terms of output growth in the counterfactual analyses. Further, the framework offers insights into the effects of any exogenous persistent time delay on firms, even in developed countries where border delays may not be relevant. Many factors can trigger such delay on firms inputs: strike in the transportation, logistics or mail sectors, disruptions of supply chains, or sanitary threat like the late COVID-19 that hampers international movements of people and goods, thereby interrupting supply chains integration (Bonadio, Huo, Levchenko, and Pandalai-Nayar, 2021).

In a closely related paper Adom and Schott (2022) analyze the effects of border delays on firms' technology choice and factor misallocation. The present paper, in contrast, studies the aggregate effects of border delays in a relatively tractable framework that allows for the derivation of analytical results. Furthermore, I am able to pinpoint the exact transmission mechanism of border delays. These include the interplay of the positive effects of ex-ante risk and the negative effects of realized delays. In addition, the present paper extends the analysis by separably calibrating the model economy to a wide set of sub-Saharan African economies, thereby taking country specificities (border delays, the share of imported goods, etc.) explicitly into account.

The rest of the paper is organized as follows. In section 2 I present some data facts and discuss the possible causes of the border delays in SSA. Section 3 presents the model, and section 4 some analytical results. The calibration strategy and the quantitative results follow in section 5 . The conclusion comes in the last section.

2 The data

This paper uses data mainly from the World Bank Enterprise Surveys (WBES). A WBES is an establishment-level survey of a representative sample of an economy's non-agricultural formal private sector. In the rest of the paper I use *firm* for convenience to designate *establishment*. Respondents are business managers. The surveys use a global methodology that includes standardized survey instruments and a uniform sampling methodology across countries, and cover a broad range of business environment topics. The Enterprise Surveys are cross-sectional and repeted for some countries in different years. Therefore, some countries have been surveyed more than once. But I just consider the latest year, and I retain Sub-Saharan African countries that have been surveyed from 2009 onwards.[7] Thus 42 countries are under consideration. A complete list of the countries is provided later in the paper. Not only is the WBES one of the rare firms' data source in Sub-Saharan Africa, it is also deemed to be of high quality and has been used in many recent papers including Ranasinghe and Restuccia (2018), Besley and Mueller (2018), and Atkin and Donaldson (2021). The data are publicly and freely available on the WBES portail. From this database I compute the proportion of firms importing material inputs or supplies, the average time material inputs or supplies remain in customs and the proportion of imported material inputs or supplies.

In addition, I use data from the UNCOMTRADE database, which I aggregate along with the classification of Broad Economic Categories (BEC) that classifies imported inputs into capital equipment or materials.This allows me to compute the proportion of capital and materials in the imported inputs. I get some other macro data from the World Bank's World Development Indicator (WDI) database.

2 .1 Long delays of imported inputs at borders

The WBES reports firm-level average number of days imported inputs remain in customs until they are available to be claimed by the owner. Figures 2.1 and 2.2 show that border delays feature great variabilities within and across countries. Long border delay is widespread all over SSA, with a few exceptions. In countries like Burundi, Chad, and Mali the average border delay amounts over 30 days. In many countries, the maximum firm's average border delay of inputs is greater than 150 days. Even the *best students* in terms of faster border procedures feature maxima of firm-average border delay of two months or more. For comparison, the average border delay is about 2.6 days in Sweden, 5.7 in Germany and Spain, and 6.5 days in Italy and Thailand.

So, why are border delays so long in SSA compared to the rest of the World ? Montagnat-Rentier and Parent (2012) identified many factors including poor infrastructures, but according to Djankov, Freund, and Pham (2010), about 75% of the delays are due to administrative hurdles, including red tape and redundant inspections.

Indeed, border administrations performance is still very limited in SSA.[8] The World Economic

[7] Because the WBES is better harmonized accross countries from 2009 onwards.

[8] See for e.g. The World Economic Forum and The Global Alliance for Trade Facilitation (2016); Hoffman et al.

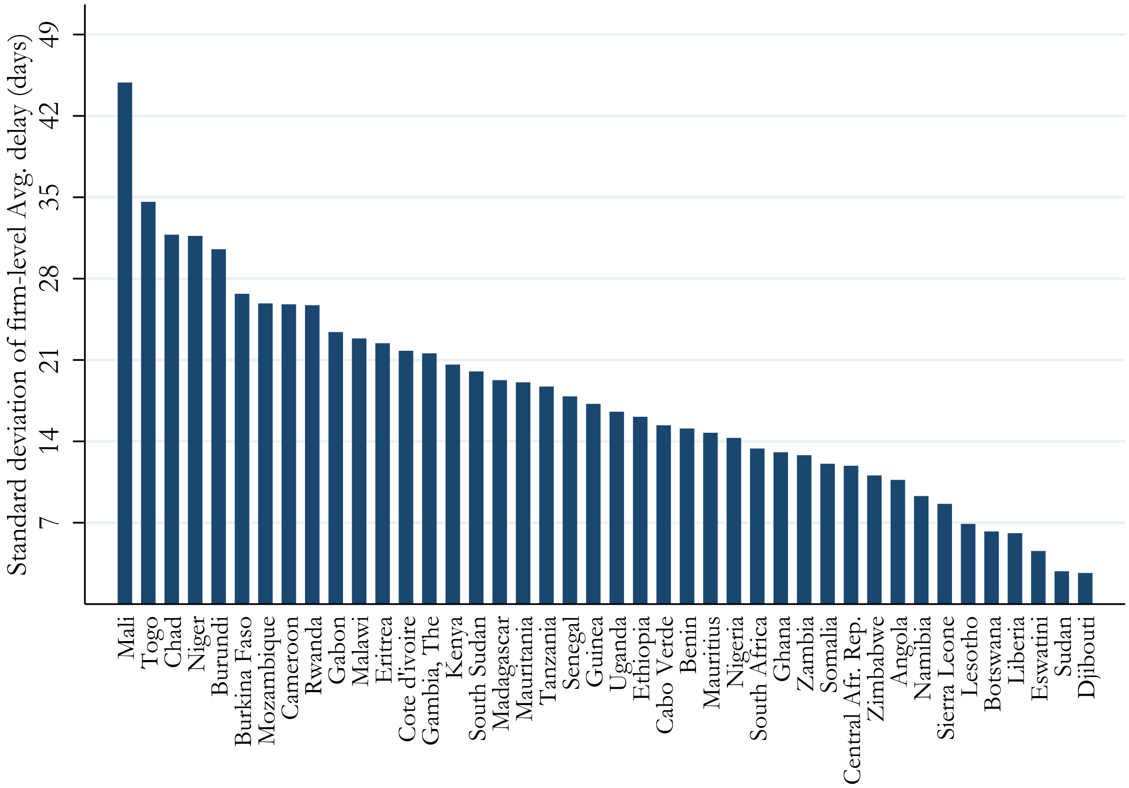

Figure 2.2: Standard deviation of firm-level average import delay in Sub-Saharan Africa. Source: WBES data and author's calculations.

Forum (WEF) assesses and ranks the easiness of international trade in a large sample of countries around the world. My calculations based on the indicators of the WEF's 2012 report show that the 28 SSA countries included in the sample of 132 countries ranked on average 100 with an average score of 3.2 on a 1-to-7 scale of border administration efficiency score, where 1 stands for "extremely inefficient" and 7 for "extremely efficient". This reflects burdensome customs procedures and regulations in these countries, constituting a hurdle for firms that import capital and intermediate goods. For example, importing goods into South Africa – the most economically developed country in the region – takes 32 days, requires 8 documents in 2012, while the customs administration of Nigeria – the second most economically developed country in the region – is among the least transparent (116th) and least efficient (115th) in the world (The World Economic Forum, 2012). In the same logic, Barka (2012) conducted a research and discovered that the average customs transaction in Africa involves 20–30 different parties, 40 documents, 200 data elements (30 of which repeated at least 30 times), and the rekeying of 60-70% of all data at least once. These facts are corroborated by Djankov et al. (2010).

These confirm the consensus in the literature that border administrations in SSA countries are

(2016); Barka (2012); Ocean Shipping Consultants, Ltd. (2008)

burdensome.[9] Also, some testimonies of business owners from SSA corroborate these facts.[10] For example, the head of logistics for a Kenyan garment exporter said: "There are so many processes, so much documentation [...]".[11]

2 .2 A significant proportion of imported inputs

The WBES data also report the proportion of inputs (capital and materials) sourced from local and foreign origins. This information is important for the goal of this paper. In fact, the border delay is likely to matter less if only few quantity of inputs is imported. But Figure 2.3 shows that the proportion of foreign inputs is substantive in most SSA countries. In more than half of the countries, this proportion exceeds 40%, and in some cases it reaches more than 60%. Only 5 countries have a proportion of imported inputs of less than 20%, the lowest (3.5%) being in South Africa.[12]

2 .3 Materials and intermediate goods prevail in imported inputs

The nature of the delayed inputs is also critical for the goal of this paper. Broadly, I distinguish between two types: capital goods and materials goods. In essence, materials are capital goods with full depreciation. If hypothetically the inputs do not depreciate at all, then the delays will have very limited impact if any. With no financial constraints the firm would order once for all the optimal amount of foreign inputs it needs. When it will finally be delivered, the firm will no longer need to import inputs, neither will it be subject to delays even if the border administrations continue to perform poorly. On the other hand, if imported inputs are materials that fully depreciate after a period, the effect of the delays will be the worst. Thus, the structure of the imported inputs is sensitive in the analysis.

Figure 2.4 shows the proportion of materials in imported inputs in some SSA countries, using data from the UNCOMTRADE. In most countries, the proportion of materials is comprised between 50% and 80%, outweighing largely that of capital.

2 .4 Negative correlation between border delays and GDP per capita

Figure 2.5 shows that the average border delay is negatively correlated with the real GDP per capita across SSA. Countries that have lower average border delay tend to have higher real GDP per capita, and vice-versa. For instance, Botswana, Namibia, and South Africa are among the few

[9] See Hoffman et al. (2016); The World Economic Forum and The Global Alliance for Trade Facilitation (2016); The World Economic Forum (2014); Valensisi and Lisinge (2013); Barka (2012); The World Economic Forum (2012); Djankov et al. (2010); Ocean Shipping Consultants, Ltd. (2008)

[10] See https://theprepared.org/features-feed/2018/12/22/the-supply-chain-africa-needs, https://www.weforum.org/agenda/2016/12/africa-trade-regulation-red-tape-getr-2016/, and https://www.thebusinessyear.com/nigeria-2018/jude-abalaka-managing-director-tranos/vip-interview

[11] See The World Economic Forum and The Global Alliance for Trade Facilitation (2016)

[12] The proportion abnormally low found in South Africa is certainly linked to the year of the survey which is 2020 in this country. Due to the COVID-19 pandemic, international movement of goods is substantively reduced all over the world.

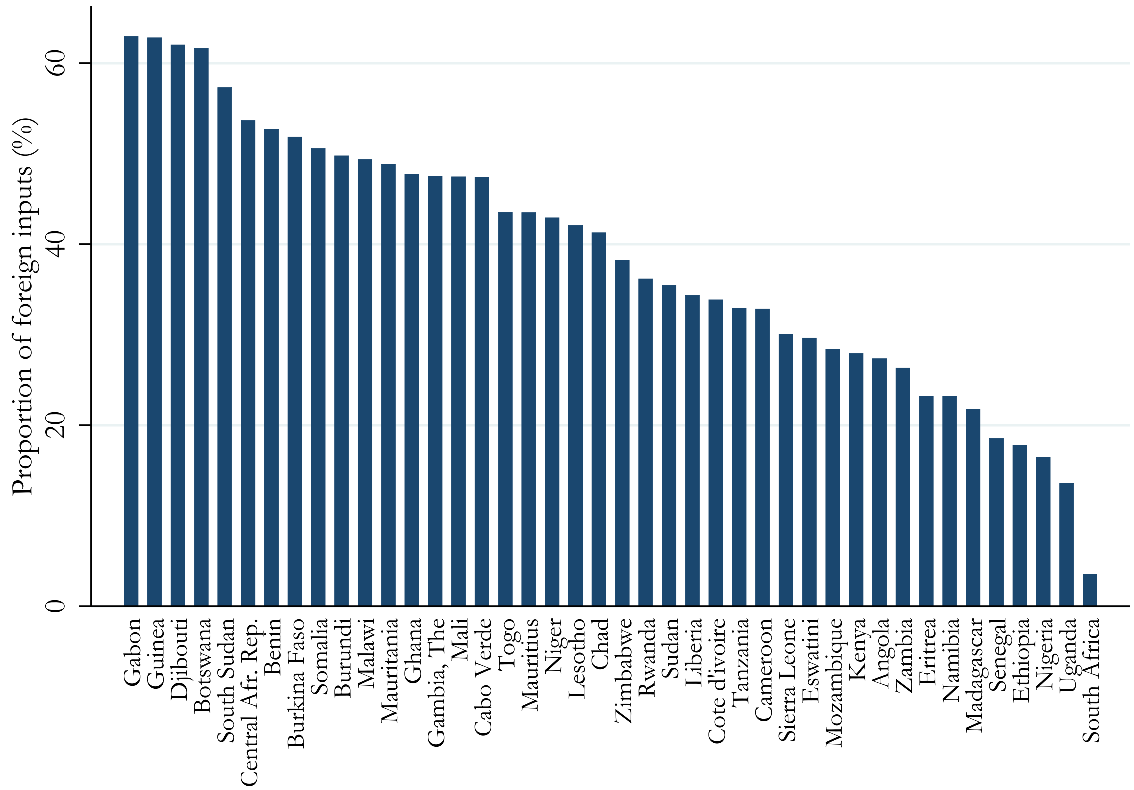

Figure 2.3: Average proportion of foreign inputs by country. Source: WBES data and author's calculations.

SSA countries that are upper-middle-income economies in the World Bank's 2021 classification. They also have lower average border delays. On the other hand, Burundi, Mali, and Togo that have higher average border delays are also among the low-income economies, the poorest group. This fact is in line with The World Economic Forum and The Global Alliance for Trade Facilitation (2016) that found a strong positive correlation between the border administration efficiency index and the real GDP per capita in a larger sample of countries around the world.

3 The model economy

The model economy is populated by a constant mass of an infinite number of firms, and a representative hand-to-mouth household. The household supplies labor to firms from whom it receives wage income and dividend used to consume.

3 .1 Firms

Firms produce a homogeneous good, using production factors including foreign capital with a decreasing return to scale (DRS) technology.[13] I use the terms input and capital interchangeably

[13] *capital* stands for *inputs* other than labor. They include durable equipment on the one hand, and materials that are fully depreciate on the other hand. In the data, both durable equipment and materials are present within

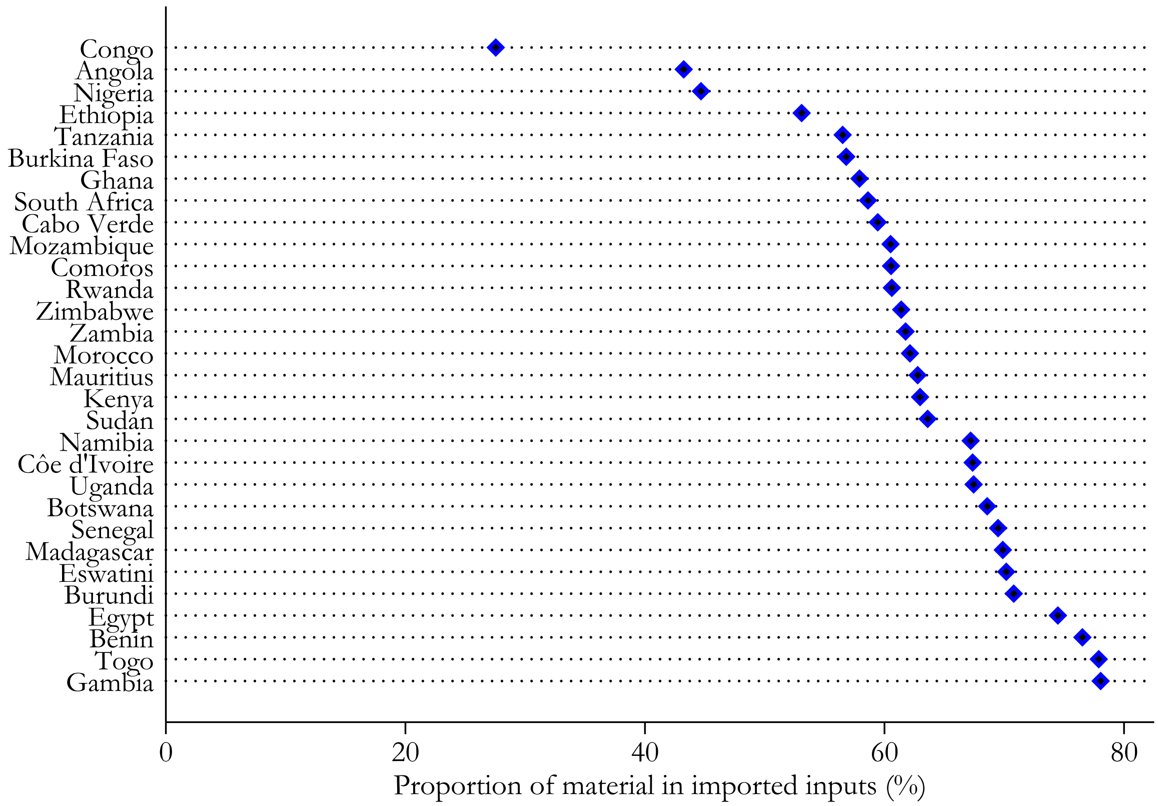

Figure 2.4: Proportion of materials and intermediate goods in imported inputs. Source: UNCOMTRADE data and author's calculations. *Note:* I aggregate the data into capital equipment or materials using the classification of Broad Economic Categories (BEC).

in the following. Firms live infinitely and accumulate foreign and local capital. I assume that any foreign capital investment order is immediately supplied and available at the border. Thus, I abstract from sourcing and transportation time and costs.[14] However, imported inputs have to comply with border regulations before they can be claimed. During the clearance process, input may be delayed, due to administrative burdens, red tape, and corruption as described in section 2 .1. So, when a firm places an investment order, it does not know when it would be delivered for sure, but has imperfect knowledge of the delivery time – based on experience – represented by a

the importation of inputs, materials representing the larger proportion except in Congo, Nigeria, and Angola. I abstract from disentangling them in my model for the sake of simplicity: distinguishing both inputs highlights the same mechanisms that I discuss later, but makes the maths and the computations harder if not impossible. On the other hand, a lot of papers make the same assumption, not disentangling between capital equipment and intermediate inputs (e.g. Chan (2017); Dissou and Ghazal (2010)). I will discuss in the calibration part how I take into account both input types in my quantitative experiments.

[14]Importation of goods involves many steps that can each take some time: search-and-match a supplier, transportation from origin place to destination border, comply with border regulations including clearance, transportation from the border to the firm place. We don't have coherent data for the whole process, but only for the border delay. Although every delay is likely to matter for firms, some sources result from endogenous choices (e.g. the choice of the supplier) and others are more predictable in terms of delay (e.g. inland transportation). The analysis focuses therefore on border delays that are rather exogenous to firms and less predictable (see the causes discussed in section 2 .1).

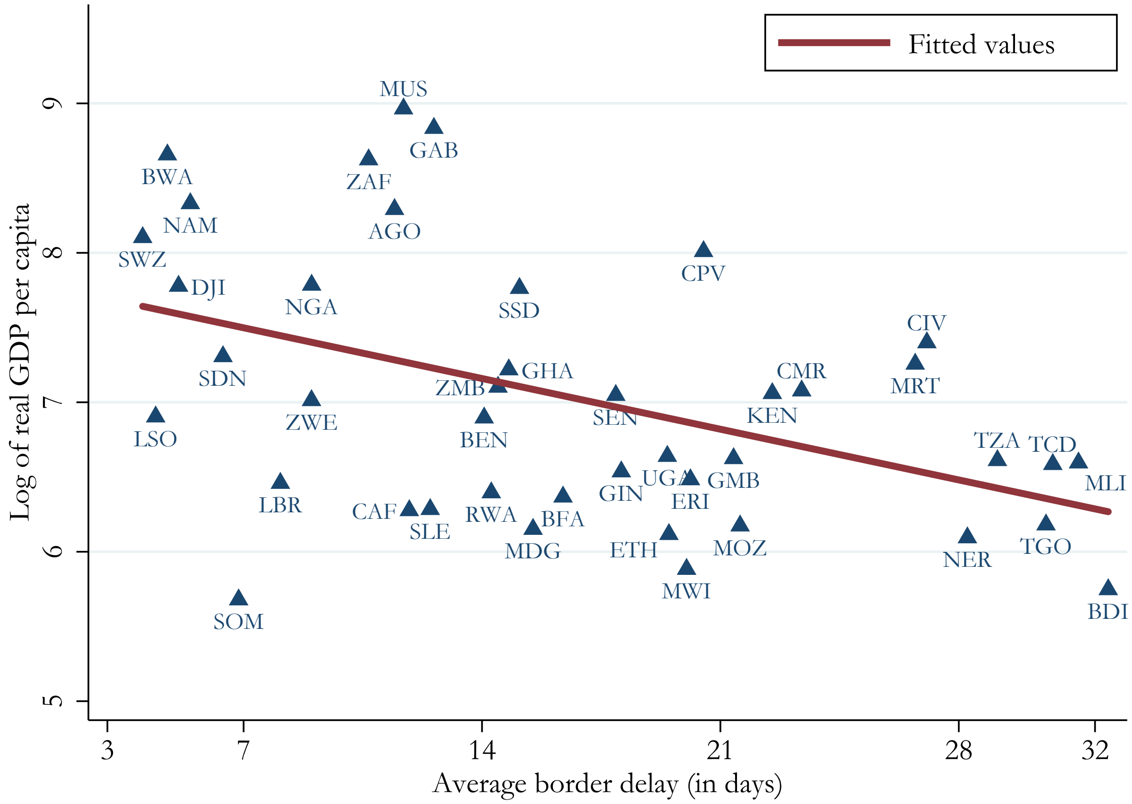

Figure 2.5: Correlation between border delay and real GDP per capita across Sub-Saharan Africa. Source: WBES, WDI and author's calculations. *Note:* The figure uses 2010 GDP per capita, in constant 2015 US $.

probability distribution G of the time delay τ (Figure 2.6).

Consider the timing represented in Figure 2.7. Because of delays, at any time a firm may have a positive amount of investment order pending at the border. After production, the firm decides whether to place new investment orders, $i_{f,t}$ and $i_{l,t}$, and the amount of such orders. At the beginning of next period it observes whether the investment orders arrive or not.

Let us define:

$$d_{t,t+j} = \begin{cases} 1 \text{ if } i_{f,t} \text{ arrives after } t+j-1 \text{ production, but before that of } t+j \\ 0 \text{ otherwise} \end{cases}$$

with $\sum_{j=1}^{\infty} d_{t,t+j} = 1$. That means that delivery of $i_{f,t}$ occurs at some time unknown in advance. Then the motion of foreign capital can be writen as follow.

$$k_{f,t+1} - (1-\delta_f)k_{f,t} = \sum_{j=0}^{t} d_{t-j,t+1} i_{f,t-j} \tag{2.1}$$

where δ_f is the depreciation rate of the foreign capital. According to equation (2.1), the increase

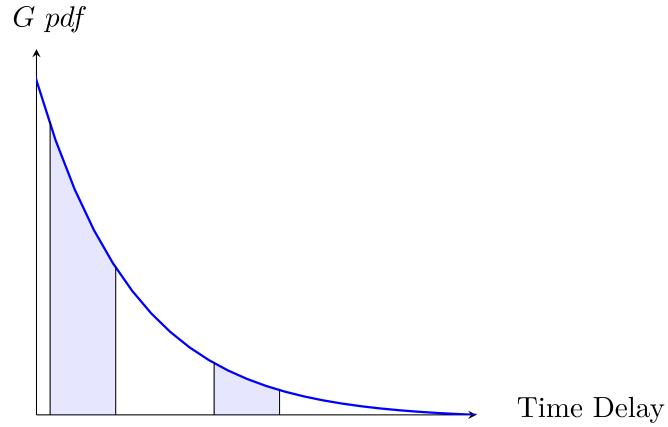

Figure 2.6: Prior knowledge on delivery process

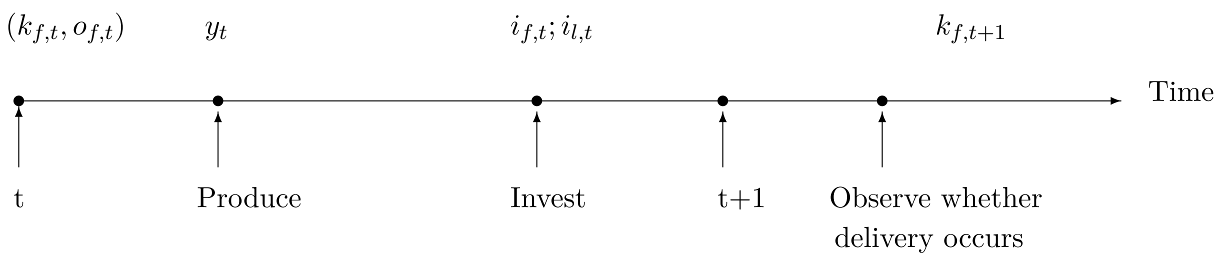

Figure 2.7: Timing

of the stock of foreign capital at the firm level net of depreciation between two subsequent periods is the sum of investment orders placed in the past that are just delivered. Because an order may not be delivered at a period due to delays at border, the net increase in the productive capital may be null even if the firm placed positive investment order. This is not the case in standard macroeconomic models where an investment enters production by the subsequent period. It is not either the case in *time to build* models. In these models, although an investment requires some periods to become productive, it is usually assumed that a constant proportion is achieved each period. So, at any period the net variation of the capital is non-null as long as the agent plans for a non-null investment.

Unlike foreign capital, local capital is not subject to any delivery delay, because it does not cross border, neither does it clear customs. Therefore, local capital's law of motion is standard:

$$k_{l,t+1} - (1 - \delta_l)k_{l,t} = i_{l,t} \tag{2.2}$$

Note that this is not a single representative firm framework. Although firms may be identical at the beginning, they become heterogeneous in the foreign capital at any period because they may and will have different realizations of delivery hazard.[15] In addition, I abstain from entry and exit

[15]This gives motivation for the DRS technology representation. CRS technology is commonly used for a representative firm because resources can be reallocated from many identical firms to one firm with no effect on aggregate

so that the mass of firms is irrelevant for the analysis.

Technology. – The technology is a DRS Cobb-Douglass of labor and composite capital of the form $y = k^{\alpha}n^{\nu}$, where the composite capital is a CES aggregation of local capital (k_l) and foreign capital (k_f), of the form

$$k = \left[\psi k_l^{\rho} + (1-\psi)k_f^{\rho}\right]^{\frac{1}{\rho}}.$$

$\sigma = \frac{1}{1-\rho}$ measures the elasticity of substitution between local and foreign capital, while the parameter ψ measures the relative share of local capital.

Firms rent labor on a competitive spot market for a wage w. Hence the profit of a firm that operates with $k_{l,t}$ unit of local capital, $k_{f,t}$ unit of foreign capital and n_t unit of labor is $y_t(k_{l,t}, k_{f,t}, n_t) - wn_t$. By maximizing this expression with respect to n_t we find $\pi_t(k_{l,t}, k_{f,t}) = \Gamma \cdot k_t(k_{l,t}, k_{f,t})^{\tilde{\alpha}}$, where $\Gamma = w\left(\frac{\nu}{w}\right)^{\frac{1}{1-\nu}}\left(\frac{1}{\nu} - 1\right)$ and $\tilde{\alpha} = \frac{\alpha}{1-\nu}$.

Problem of the firm. – Future values are discounted with the factor β. The value of a firm consists in the discounted sum of present and future profit flows. A firm maximizes its value by choosing investments in local and foreign capital. At this stage, the value of a firm depends on the history of amount and delivery of all past investments that the firm had made, $\mathcal{H}_t = ((d_{t-j,t-k})_{k<j}, i_{f,t-j})_{1\leq j\leq t-1}^{\infty}$. It is a high dimensional object that is difficult, if not impossible, to numerically solve. To bypass this, I make the simplification assumption that at a given period a firm receives all its outstanding orders or receives none of them. Thus, $\mathcal{H}_t$ is reduced to the triplet $(o_{f,t}, z_t, \theta_t)$ where z_t is a binary variable whose value is 1 with probability θ_t if the sum of outstanding orders $o_{f,t}$ is delivered (or cleared) and 0 otherwise. For simplicity I assume that $\theta_t = \theta$ is constant over time and for all firms. This assumption can be released by letting z_t be a first order Markov binary process. This would better represent a *first-in-first-out* organization at the customs; but it is not necessary for the mechanism of input disruptions in the model.[16]

I define the value of a firm *after* production and *before* investment orders are placed. So, the laws of motion of the states $k_{f,t}$ and $o_{f,t}$ at that time are modified as in equations (2.3) and (2.4).

$$k_{f,t+1} = (1-\delta_f)\left[k_{f,t} + z(o_{f,t} + i_{f,t})\right] \tag{2.3}$$

$$o_{f,t+1} = (1-z)(o_{f,t} + i_{f,t}) \tag{2.4}$$

With this *new* timing, $k_{l,t}$ needs not to be a state variable.[17] The investment choice problem of the firm in the form of a Bellman equation is written as follows.

production. In the case of this paper, firms are heterogeneously subject to delivery hazard and this hypothetical reallocation can not be.

[16]Most important, representing z_t as an *i.i.d* process is technically more convenient because then it is not a state variable.

[17]Implicitly, the firm sells out its outstanding stock of local capital after production and repurchase it at the beginning of next period.

$$
\begin{aligned}
V(k_f, o_f) = \underset{k_l, i_f}{max} \ & \left\{ \left[-1+\beta(1-\delta_l)\right] k_l - i_f + \beta \mathbb{E}_z \left[\pi(k_l, k_f + z(o_f + i_f)) + V(k'_f, o'_f) \right] \right\} \\
\text{s.t. } k'_f &= (1-\delta_f) \left[k_f + z(o_f + i_f)\right] \\
o'_f &= (1-z)(o_f + i_f) \\
k_l,\ i_f &\geq 0
\end{aligned} \tag{2.5}
$$

It is worth clarifying two points here. First, since there is no price for foreign capital, I am implicitly assuming that foreign and local capital have the same price, which is equal to that of the final good. In other words, the final good produced by the local firms could be transformed into foreign capital at the ratio one to one, but that does not take place within the local economy. This assumption is clearly unrealistic, but it is conservative because in reality the price of foreign capital is likely to be higher, or equivalently the transformation ratio would be less than one.[18] Second disinvestment is possible for local capital but not for foreign capital. So the only way to "consume" foreign capital in the setup is by using it for production. This assumption technically implies that problem (2.5) does not write consistently in finite horizon simply *mutatis mutandis* as it is the case in most macroeconomic dynamic programming problems. Still the assumption is interesting because it imposes the restriction that an investment order pending at the border cannot be resold before it is cleared. It is possible to allow for disinvestment after clearing, at the firm level. But this may require additional equations and technical complications that I abstain from.

3 .2 Household

On the other side of the economy there is a representative household supplying labor service at the wage w on a competitive market, and deriving utility from consumption of the final good and from leisure. Preferences are separable, represented by the utility function $U(C_t, N_t) = Log(C_t) - \chi N_t$, where N_t is the time fraction spent working in production firms, and χ is the parameter of labor disutility. The household resources consist in labor income $w.N$ and dividend from firms, $D = \int(\pi_i - i_{i,f} - i_{i,l})di$, which is the balance of profits after investments. The household consumes all its income. Some algebra help derive the household labor supply $N^s = \frac{1}{\chi} - \frac{D}{w}$.

3 .3 Stationary competitive equilibrium

A stationary competitive equilibrium in the model is a vector $(w, i_f, k_l, n, C, N, F(k_f, o_f, z))$ of wage, policy functions and an invariant distribution such that:

i) i_f, k_l and n optimize the firms' problem, given w;

[18] The parameter ψ that captures the relative share of local capital in total cost of capital is related to prices and quantities of both capital. The assumption of same price mutes the price effect and ψ captures only the relative quantities.

$ii)$ C and N optimize the household's problem, given w;

$iii)$ the labor market clears:
$$N = N^s = N^d = \sum_{z=0}^{1} \int n\,(k_f, o_f, z)\, dF(k_f, o_f, z);$$

$iv)$ the aggregate resource constraint holds:
$$Y = \int y(k_f, o_f, z) dF(k_f, o_f, z) = C + \int \left[i_f(k_f, o_f, z) + i_l(k_f, o_f, z)\right] dF(k_f, o_f, z)$$

$v)$ The distribution $F(k_f, o_f)$ is consistent and stationary:
$$\begin{aligned} F(k'_f, o'_f) =& \mathbb{P}(z = 1) F(k'^{-1}_f(k_f, o_f), o'^{-1}_f(k_f, o_f))|_{z=1} + \\ & \mathbb{P}(z = 0) F(k'^{-1}_f(k_f, o_f), o'^{-1}_f(k_f, o_f))|_{z=0} \end{aligned}$$

Although the model is simple, it does not have an analytical solution in its general form because of the CES aggregation. I consider some specific simplified cases and derive interesting analytical results in the next section.

4 Analytical results

The full model as presented above does not have analytical solution. In this section, I consider some specific simplified cases and derive analytically the effects of the delays on the net present value of investments and on foreign inputs accumulation.

4 .1 Border delays and investment's net present value

In this subsection, I highlight the effect of border delays on an investment's net present value. Let us consider a firm that invests $i_{f,t}$ in foreign capital goods at time t in the model economy presented above. Assume technology is $y_t = k^{\alpha}_{f,t}$, i.e, foreign capital is the only input. Further suppose that the firm has no stock of capital and places no other investment from period $t + 1$ and afterward. Thus, we keep track on the one stream of investment $i_{f,t}$, and compare its net present value under and without border delays.

In the standard case where there is no delay, $i_{f,t}$ would be used in the production process from period $t + 1$. Then, the net present value of that investment is:

$$NPV_0(i_{f,t}) = -i_{f,t} + \sum_{j=1}^{\infty} \beta^j \left[(1 - \delta_f)^{j-1} i_{f,t}\right]^{\alpha} \tag{2.6}$$

The first term in equation (2.6) is the investment cost, while the second term is the discounted return on that investment in future periods through production flows.

In presence of border delays delivery may occur later. The agent knows only the distribution of delivery probability over time, $m = (p_1, p_2, ...,)$, with $p_k \geq 0$, $\forall\ k = 1, 2, ...$, and $\sum_{k=1}^{\infty} p_k = 1$

(Figure 2.6). p_k is the probability that the order is delivered after k periods. Then the expected net present value of the investment $i_{f,t}$ under this friction is:

$$NPV_m(i_{f,t}) = -i_{f,t} + \sum_{k=1}^{\infty} p_k V^{(k)}(i_{f,t}) \tag{2.7}$$

where $V^{(j)}(i_{f,t}) = \beta^j i_{f,t}^{\alpha} + \beta^{j+1}\left[(1-\delta_f)i_{f,t}\right]^{\alpha} + \beta^{j+2}\left[(1-\delta_f)^2 i_{f,t}\right]^{\alpha} + \beta^{j+3}\left[(1-\delta_f)^3 i_{f,t}\right]^{\alpha} + ...$ is the discounted value of future revenues from $i_{f,t}$, if $i_{f,t}$ is delivered at time $t+j$. The *time to build* of j completion periods (Kydland and Prescott, 1982; Chang, 1995) is nested by the discrete probability distribution that places the weight 1 at the $(t+j)^{th}$ period, $m_j = (0, 0, ..., 1, 0, 0, ...)$. In particular, the standard representation – no delays and no time to build – corresponds to the m_1 probability distribution, while the m_∞ probability distribution corresponds to loss of orders. It is straightforward that $NPV_0 = NPV_{m_1}$ and the following propositions, whose proofs can be found in annexes 1 .1 and 1 .2, hold.

Proposition 1 *If $\beta < 1$, then:*

(i) the net present value of an investment is lower when it is subject to delays than when it is not subject to delays: $NPV_m \leq NPV_0$, $\forall$ m and $NPV_m < NPV_0$, if $m \neq m_1$.

(ii) the farther a probability distribution m places higher weights (i.e the more G is left-skewed), the lower the net present value of an investment $i_{f,t}$ under this distribution.

(iii) $NPV_m(i_{f,t})$ is increasing in the discounting factor β for all probability distribution $m \neq m_1$.

Proposition 2 *If the discounting factor is $\beta = 1$, then delays do not matter whatever the probability distribution: $NPV_0 = NPV_m$, $\forall m$.*

Proposition 1 says that, if the future is discounted at strictly positive rate, then the delays depress the return to foreign capital investment and lower its net present value. In other words, all things else equal, the delays increase the opportunity cost of investment. The higher the interest rate, the worse the effects of delays. This is interesting because in SSA countries, the interest rate is much higher than in developed countries, even the risk-free interest rate of governments' bounds. This could be partly due to the fact that saving is lower in these low-income countries where populations are rather hand-to-mouth, making credit relatively scarce. On the other hand, less efficient border administrations would operate probability distributions that are more skewed to the left and thereby causing severer negative impacts. Proposition 2 however establishes that delivery delays don't matter if the future is not discounted. This result is predictable though. In reality, impatience, interest rate, financial constraints and uncertainty are all factors that justify the discounting of the future.

4 .2 Border delays and capital accumulation

Now consider the full model, in particular the firm problem in equation (2.5). Let $r = 1/\beta - 1$ be the risk-free interest rate where β is the household discounting factor. Since the model does not account for any financial friction, the means of financing investment is irrelevant. Only the optimum scales of operation (k_l^* and k_f^*) matter. The firm would like to set up these scales but delivery delays can hinder it in doing so. Abstraction from financial frictions is a conservative simplification because any financial constraint will tend to exacerbate the effect of the delays, through higher interest rate for example.

Taking the first order condition of problem (2.5) with respect to k_l, we get:

$$r + \delta_l = \mathbb{E}_z \left[\frac{\partial \pi}{\partial k_l}(k_l, k_f + z(o_f + i_f)) \right] \tag{2.8}$$

The left-hand side of equation (2.8) is the actual usage cost of the local capital. Recall that z is a dummy equal one with probability θ and zero with probability $(1-\theta)$. If local and foreign capital are perfect complements, then the marginal profit of the local capital is increasing in the amount of operating foreign capital: $\frac{\partial \pi}{\partial k_l}(k_l, k_f + o_f + i_f) \geq \frac{\partial \pi}{\partial k_l}(k_l, k_f)$. This implies that the right-hand side of equation (2.8), the expected marginal return to the local capital under delivery delays is lower than the frictionless return to the local capital $\frac{\partial \pi}{\partial k_l}(k_l, k_f + o_f + i_f)$. Consequently, the optimum scale of operating local capital is lower under the delivery delays. Thus, if local and foreign capital are perfect complements and if $\beta < 1$, then the optimum scale of local capital is lower under the delivery delays.

However, if local and foreign capital are imperfect substitutes the marginal profit of the local capital may be increasing or decreasing in the amount of foreign capital depending on their degree of substitutability σ. So the effect of the delays on the local capital may reverse depending on the interaction between the discounting factor (β) and the substitutability σ. Indeed, if local and foreign capital are perfect substitutes and if $\beta < 1$, then the optimum scale of local capital is greater under the delivery delays (proposition 4 .2). This result is intuitive and works as follows. The delivery delays depress the value of an investment in foreign capital. But if local capital can perfectly substitute to foreign capital, one can avoid the supplementary delay-related costs by just reallocating investment from foreign capital to local capital. Thus, if local and foreign capital are perfect substitutes and if $\beta < 1$, then the optimum scale of local capital is greater under the delivery delays.

Likewise we can write the first order condition of the problem (2.5) with respect to i_f:

$$\begin{aligned} 1 + r =& \theta \left[\frac{\partial \pi}{\partial i_f}(k_l, k_f + o_f + i_f) + \frac{\partial V}{\partial i_f}\left((1-\delta_f)(k_f + o_f + i_f), 0\right) \right] \\ &+ (1-\theta)\frac{\partial V}{\partial i_f}\left[(1-\delta_f)k_f, o_f + i_f\right] \end{aligned} \tag{2.9}$$

If $\beta < 1$, then $\frac{\partial \pi}{\partial i_f}(k_l, k_f + o_f + i_f) + \frac{\partial V}{\partial i_f}\left((1-\delta_f)(k_f + o_f + i_f), 0\right) \geq \frac{\partial V}{\partial i_f}\left[(1-\delta_f)k_f, o_f + i_f\right]$. So the certain return on the foreign capital investment is higher than the expected return under delivery uncertainty. But the effect on foreign capital in a dynamic setting also depends on the input disruptions effect of the border delays. In fact, there is a negative effect due to lower return on investment. There may also be a positive effect due to anticipation of possible input break. Hoarding foreign input may therefore help build buffer to self-insure against the breaks. The threat of inputs break depends on the length of the delays (or the probability of delivery each period) and on the depreciation rate (or the nature of the inputs). The numerical experiments in section 4 show indeed positive effect of delays on foreign inputs investment orders and a negative effect on foreign inputs stock.

In the following, I calibrate the parameters of the model, solve it numerically and perform counterfactual simulations to quantitatively measure the extent of the effects of the delivery delays established in propositions 1 through 4 .2.

5 Quantitative analysis

This section presents the calibration strategy and the counterfactual analyses performed to gauge quantitatively the effects of border delays in SSA.

5 .1 Calibration

Because countries that perform best clear imported inputs within a week, the model period is set to a week in order to better benchmark the delivery parameter. I calibrate most of the parameters outside the model, based on the literature and the data. The global return to scale $(\alpha + \nu)$ is set to 0.85, two thirds of which is directed to labor. So, the labor share ν is set to 0.5667 and the capital share α to 0.2833, which are in the range of the values commonly used in the literature (Restuccia and Rogerson (2008) and references therein).

The capital depreciation rates calibration proceeds as follows. First, I assume that local and foreign inputs depreciate at the same rate ($\delta_l = \delta_f = \delta$) for the sake of technical and computational easiness.[19] Second, recall that *capital* in the model stands for a *mixture of capital equipment and materials*. As discussed previously in section 2 .3 the structure of imported inputs is potentially sensitive for the analysis. However, no distinction between capital equipment and material inputs is made in the model because the mechanism is the same for both and disentangling them would only add to the state variables, making the computation harder since there is no closed form solution for the problem with the CES specification. Indeed, material inputs are virtually capital inputs with unity depreciation rate. Therefore, I compute the average depreciation rate between capital equipment and materials, weighted by the relative proportion of each in total imported inputs. Namely, $\delta = \omega_k \delta_k + \omega_m \delta_m$, where δ_k and δ_m are the depreciation rates of capital and materials respectively, and ω_k and ω_m are the proportions of capital and materials within total imported inputs respectively.[20] Finally, δ_k and δ_m are set to 10% and 100% *per year*, respectively. In

[19] Setting the same depreciation rate for both local and foreign capital simplifies the derivation of the steady state of the frictionless model, and the computation strategy.

[20] Chang (1995) proceeds likewise to compute the depreciation of the mixture of capital equipment and capital structure, although this approach does not take into account the differential of substitutability that may exist between the different production factors. Besides, the relative share of materials and capital is not available in the data for

appendix 3 .2 I analyze how sensitive to the imported inputs structure the results are.

The future discounting factor, β is set to 0.9985, corresponding to the median yearly-average risk-free interest rate of 7.8% while the disutility of labor χ is calibrated endogenously to match the labor supply to 1/3.[21] The parameters σ and ψ are yet to be calibrated.

I calibrate ψ internally to match the intensity of foreign inputs – $k_f/(k_l + k_f)$ – in the frictional model with that in the data. I encountered not many studies in the literature that deal with the elasticity of substitution between local and foreign inputs σ. Boehm, Flaaen, and Pandalai-Nayar (2019) computed the substitutability between Japan originated material inputs and non-Japan originated material inputs in the U.S. and found an elasticity of 0.2 or less. They concluded that the substitutability of Japanese-produced intermediates with other inputs is very low. Other papers dealt with elasticity of substitution between inputs more generally and tend to suggest that inputs are not much substitutable (Chan, 2017; Barrot and Sauvagnat, 2016; Krusell, Ohanian, Ríos-Rull, and Violante, 2000; Chang, 1995; Recka, 2013). In the numerical experiments I set σ equal 0.8, which is a middle value within the range of the estimates in the literature as I show in appendix 3 .1 . I also perform robustness checks in the same appendix for other values of σ and found that the results do not change significantly for σ equal 0.5, while they are stronger with $\sigma = 1.5$ and much less stronger with $\sigma = 2$.

The delivery probability θ is calibrated as follows. I observe in the data the average number of days inputs are delayed at borders. Following Heer and Maussner (2010), I compute the probability of delivery within a week in a country with an average border delay of μ days as $\theta(\mu) = min(1; \frac{7}{\mu})$. This is based on a simple rule of three and the principle is intuitive. If in a country inputs are delayed for two weeks (14 days) on average, then delivery occurs on average once in two weeks and the probability of delivery within a week is 1/2.[22] Thus, $\theta(\mu)$ equals 1 in any case inputs clear within a week, and less than 1 otherwise. The poorer the efficiency of the border administration the longer the border delays and the lower the probability θ. In particular, the model considers the clearance efficiency level in countries like Germany, Ireland, etc. as the best-ever that can be achieved. Any customs clearance delay of less than one week is not distorting in the analysis. This assumption is limited compared to the reality where even one day delay could be a big deal for a firm. For example, Hummels and Schaur (2013) found that a one-day delay triggers 0.6% to 2.1% ad-valorem lost of consumption good from the consumer perspective while parts and components are 60% more time sensitive. However, I believe that a weekly period in the model is fairly short. Generally, macroeconomic models are assumed to be annual or semi-annual. Most importantly, this way of benchmarking the analysis is appealing for policy since it would be unrealistic to wish border administrations to eliminate border delays totally, but one can expect them to catch up with the best practices in the world (Montagnat-Rentier and Parent (2012); The World Economic

some countries. For those countries, I use the sample average.

[21] For comparison, from the same database the average risk-free interest of the U.S. during the same period is 1.64%, that of the Japan is 0.1%; and the average lending rate in China is 5.47%.

[22] Heer and Maussner (2010) used this approach to calibrate the probability of getting a job, knowing the average unemployment duration. See page 361.

Table 2.1: External calibration

Parameter	Symbol	Value
Capital inputs share	α	0.2833
Labor share	ν	0.5667
Depreciation rate	δ	0.1454
Discounting factor	β	0.9985
Elasticity of substitution between local and foreign capital	$1/(1-\rho)$	0.8

Table 2.2: Internal calibration (Cameroon)

Parameter	Value	Moment	Target	Model
θ	0.30	Average border delay	23.39	23.29
ψ	0.6250	Foreign inputs intensity	32.8%	32.98%
χ	2.3817	Working time fraction	1/3	0.3258

Forum (2012); Hoffman et al. (2016)).

Table 2.1 summarizes the external calibration for all countries, and Table 2.2 shows the parameters internally calibrated for the Cameroon economy.[23] The same procedure is followed for each country of the sample in section 5 .2.4.

5 .2 Results

The model is solved using the value function iteration method (to solve the firm problem) and a Monte-Carlo approach (to compute the stationary distribution of inputs).[24] By construction the frictionless economy corresponds to that with a delivery probability $\theta = 1$. So the baseline is the situation where $\theta < 1$ for most countries and the counterfactual consists in shutting down the delays by setting θ to 1, anything else equal. In the following, I first present the results of the quantitative analyses in detail for Cameroon. Then I present some quantitative summaries for the sample of SSA countries and draw some comparisons.[25] For example Ethiopia and Uganda are both median countries in terms of average border delay, which is 19.4 days. But they differ in their reliance on foreign inputs for production: the average percentage of firms' purchases of material inputs of foreign origin (i.e. $k_f/(k_l+k_f)$) in Uganda in 2014 was 13.6% whereas that of Ethiopia in 2015 was

[23] Cameroon is nearly a median country in regard to the dimensions of the economy's structure that are relevant for the analysis: average border delay, and proportion of imported inputs. The relative shares of imported capital and materials data are not available for that country. Therefore, I impute this moment with the sample mean of countries that have the data.

[24] Adapted from the Monte-Carlo simulation developed in Heer and Maussner (2010), p.353-355

[25] I exclude South Africa for this exercise, because the WBES is run there in 2020-2021, during the COVID-19 pandemic. This undermines for sure the comparability of South Africa WBES with the other countries, if not the quality of the survey per see. For example, the average proportion of imported inputs is only 3% for that country. That reflects certainly the effect of international supply chains break implied by the pandemic.

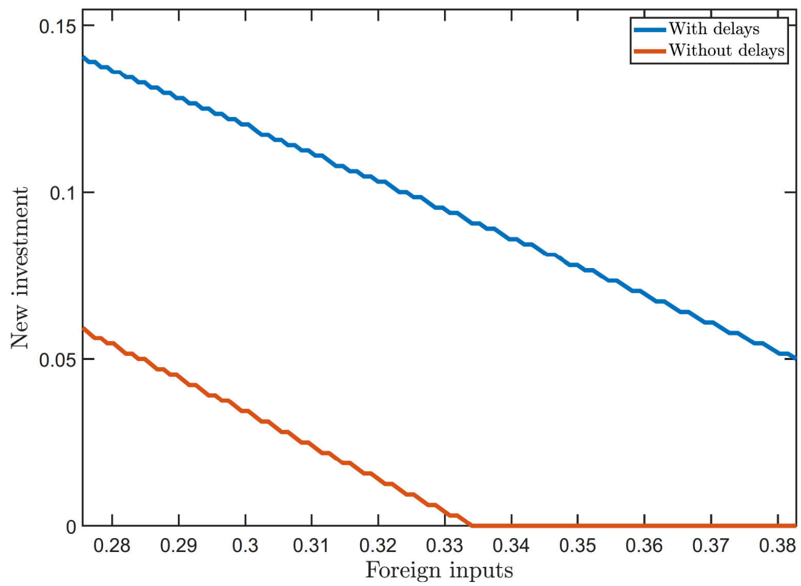

Figure 2.8: Effect of the border delays on investment order.

17.8%. This leads to different degrees of the impact of the delays in these two countries. There is also such a pattern between Nigeria and Zimbabwe, and between Senegal and Guinea.

5 .2.1 Input hoarding

In Figure 2.8 I plot the firm's investment in foreign inputs in the baseline and in the frictionless models. First, as expected new order of foreign inputs is decreasing in the firm's foreign input and there is inaction when the firm's foreign inputs exceed a certain threshold.[26] Second, foreign inputs investment is higher in the frictional model compared to that in the frictionless one. This *overinvestment* is not at odds to the statement from proposition 1 that the delivery delays lower the return on investment. Rather, it reflects a strategy to mitigate the input disruptions effect of the border delays - that I will discuss soon - and depends on the nature of the inputs being imported, namely either materials or capital.[27] Most importantly, overinvestment is consistent with input hoarding behavior observed in the countries under review. Business owners in Kenya, South Africa, and Nigeria have been asked how they cope with long delays due to international supply chains. They often reported that they order a large quantity of inputs far in advance.[28]

Input hoarding is indeed a means of self-insurance against *ex-ante risk* of input disruptions. In Figure 2.9 I simulate a firm with *systematic ex-post delivery.* This means that *ex-ante* there is

[26] The model has (s, S) investment feature because of irreversibility and partial depreciation of foreign capital. In the baseline model, the new investment is also decreasing in the firm's outstanding order, which I do not show here.

[27] In the analysis reported here, materials dominate imported inputs (62%). When I perform the same analysis assuming that imported inputs are capital goods only, I find that the new investment order is lower under the delivery hazard.

[28] See https://www.thebusinessyear.com/nigeria-2018/jude-abalaka-managing-director-tranos/vip-interview and https://theprepared.org/features/2018/12/22/the-supply-chain-africa-needs

a non-null probability that the firm experiences delays, but *ex-post* I mechanically force delivery to happen.[29] So, such a firm does not experience the delay actually, but only faces a *threat* of delay. *Ex-ante*, the firm internalizes the risk of non-delivery and places a higher investment order in foreign inputs. In the figure, the stock of foreign inputs is about 30% higher in the presence of the delivery hazard compared to the frictionless case. I introduce a three-month-delay after one year of regular delivery. Due to depreciation (or intermediates consumption), the foreign inputs stock decreases significantly, falling to about 30% lower than the frictionless optimal level. Meanwhile, the pending investment orders accumulate at border.

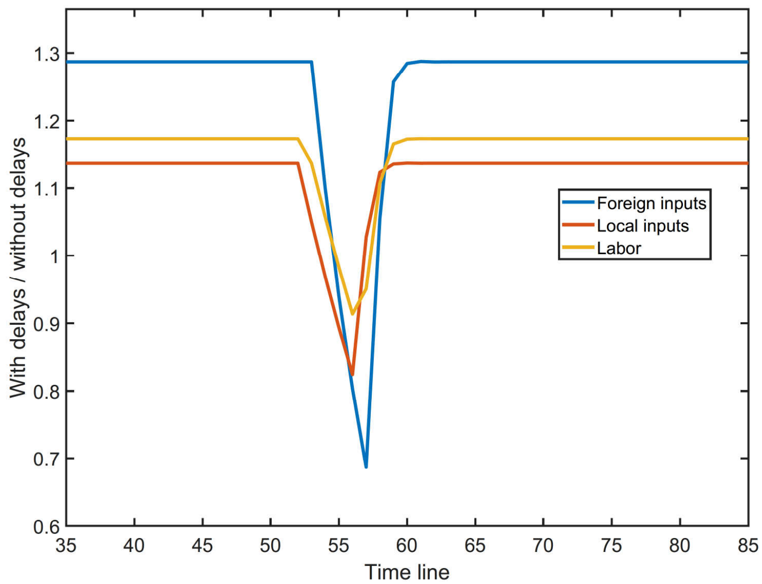

Figure 2.9: Foreign inputs subject to ex-ante risk of delay and ex-post systemic delivery.

This finding is in line with the literature that emphasizes the role of inventory keeping as shock absorber (Brummitt, Huremović, Pin, Bonds, and Vega-Redondo, 2017; Maccini, Moore, and Schaller, 2015). In particular, Alessandria, Kaboski, and Midrigan (2010) document that delivery lags induce importers to import infrequently and hold additional inventory. In the same vein, Carreras-Valle (2022) found that longer delivery delays of inputs sourced from China cause firms' inventory in the U.S. to increase since 2005.

5 .2.2 Input disruptions by border delays

Border delays trigger uncertainty and input disruptions. Figure 2.10 depicts an example of foreign inputs holding (relative to the frictionless counterfactual) by a firm through time in perspective with its delivery realizations (on the right-hand y-axis). When foreign inputs clear customs, they are delivered and the firm's foreign inputs holding increases. On the other hand, when they fail to clear customs there is no delivery and the firm's foreign inputs decrease. Interestingly, the fluctuations

[29] Technically $\theta < 1$ (induced by average delay in the data) and $z = 1$.

of the delivery process lag behind those of the foreign inputs showing that when border delay hits the firm will still have foreign inputs for some time before running out.

Figure 2.11 shows the steady state distribution of initially identical simulated firms. It shows that the delays affect firms differently. Even though they all face the same ex-ante probability of delay, the actual realizations of the delay differ potentially from one firm to another. Therefore, delays also generate heterogeneity in the effective marginal cost of investment among the firms. This potential source of misallocation of foreign capital is analyzed extensively in Adom and Schott (2022). The figure shows that most firms have lower stock of foreign inputs than the frictionless optimal level while some have more.

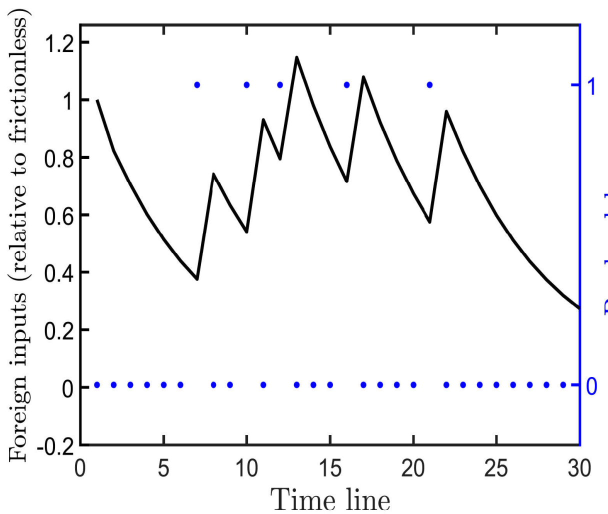

Figure 2.10: Example of a firm subject to delays.

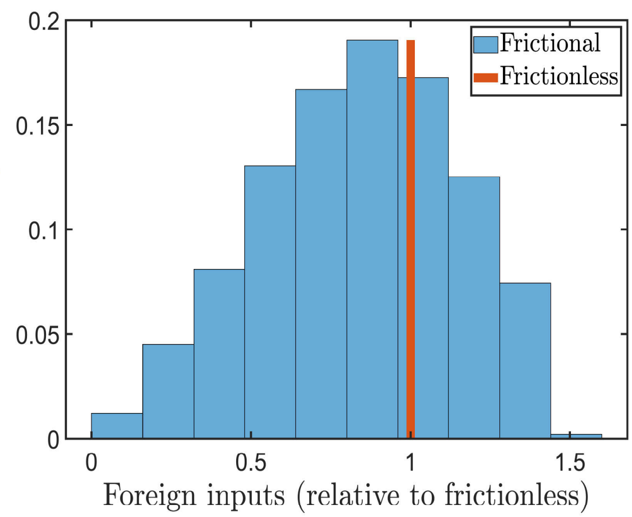

Figure 2.11: Steady state distribution of foreign inputs.

5 .2.3 Macroeconomic effects of the border delays in steady state: Cameroon

Figure 2.12 shows the effects of eliminating the border delays on some macroeconomic aggregates in steady state. Reducing the average border delay in Cameroon from 23.4 days to one week or less increases aggregate foreign inputs by 18.5% and aggregate local inputs by 2.7%. As a higher amount of foreign and local inputs raise the marginal productivity of labor its demand and the equilibrium wage increase as well. Thus, employment increases by 3.2%, and wage by 1.9%. Eventually, aggregate production increases by as much as 4.9%, and welfare as measured by consumption by 3.6%. These sizeable quantitative effects of the border delays on inputs and production are triggered not only by the relatively long delays at border in the country, but also by the preponderance of materials within the imported inputs (62%). In fact eliminating the border delays solves the input disruptions problem and allows firms to produce more. This finding is in line with the literature on the effects of input disruptions (Boehm et al., 2019; Meier, 2020).

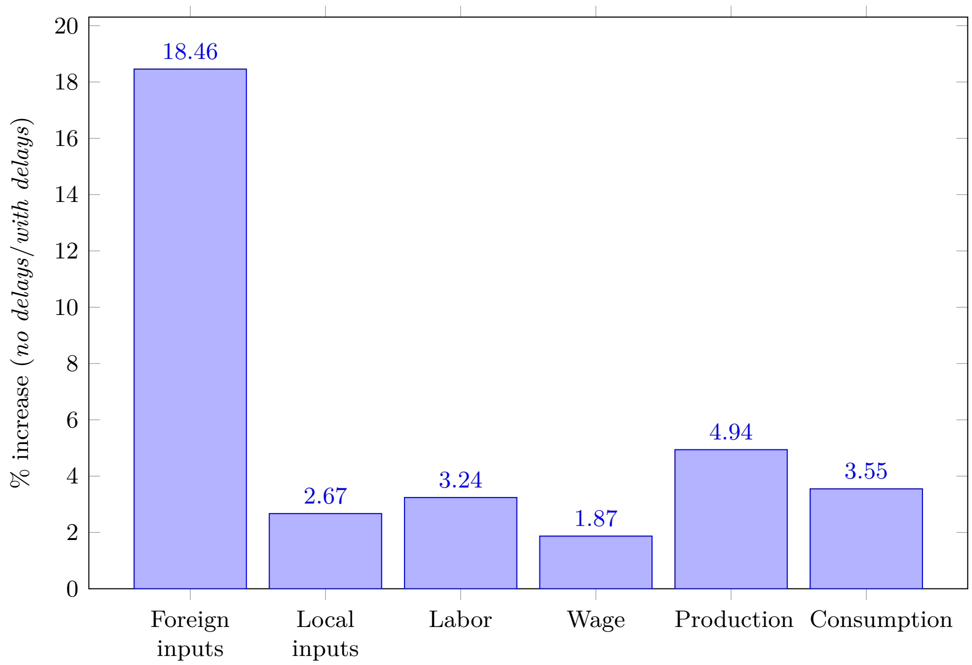

Figure 2.12: Macroeconomic effects of removing border delays. The figure shows the percentage variation of the aggregates in the frictionless counterfactual relative to their frictional value..

5 .2.4 Macroeconomic effects of the border delays in steady state: other countries

I follow the same calibration steps described for Cameroon above to calibrate the model for each of the remaining countries. The results are reported in Table 2.3. Seven countries – Botswana, Djibouti, Eswatini, Lesotho, Namibia, Somalia, and Sudan – have displayed an average delay at border less than a week. The delivery probability parameter for them is calibrated to 1; therefore they do not incur any lost due to border delays in this analysis. For the remaining countries, the gain from reducing border delays to one week or less in terms of production (respectively consumption) varies from 0.1% (respectively -0.4%) to 10.2% (respectively 6.4%), with a median of 2.7% (respectively 1.7%). The gain in terms of employment is also sizeable (more than 3% in many countries).

Importantly, the effects of border delays vary with economies' fundamentals (proportion of foreign inputs and proportion of materials in foreign inputs) as I discussed previously. For example, Ethiopia and Uganda have approximately the same average border delay of 19.4 days. However, they have different fundamentals. The former has 17.8% foreign inputs, 53% of which are material goods, while the later has 13.6% foreign inputs, 67% of which are material goods. In the results the gain in terms of production (respectively consumption) from reducing border delays to one week or less is 1.3% (respectively 0.4%) for Ethiopia, and 2.8% (respectively 2.1%) for Uganda. Similar comments can be made between Nigeria and Zimbabwe, or between Senegal and Guinea.

The poorest performance in terms of border delays is found in Burundi-2014 with 32.4 days delay at border on average. That corresponds to 22% probability of delivery within a week. The resulting gains from removing the border delays amount to an increase of foreign inputs by 29.8%, local inputs by 6.8%, aggregate employment by 2.6%, aggregate production by 8.3%, and consumption by 4.2%. On the other hand, the *best-yet-distorting* performance is met in Liberia-2017 with 8 days delay on average during clearance process and an implied probability of 88% to clear and deliver within a week. The gains from removing the border delays in this case amount to an increase of foreign inputs, local inputs, aggregate production and consumption by 0.1%, while aggregate employment decreases by 2.5%. The greatest gain in terms of production from eliminating the border delay is achieved in Chad with more than 10% increase compared to the frictional case.

5 .2.5 Discussion

The effects of the border delays estimated by my model in this paper are fairly sizeable. However, it is worth highlighting that they apply only to the formal non-agricultural economy of the related countries. That is because the WBES data are only representative of the formal economy of the countries where the surveys took place. Thus, in the case of Cameroon for example, my model predicts that, *ceteris paribus*, reducing the average border delay from 23.4 days to one week or less (70% reduction) would imply 4.9% increase in the *formal non-agricultural economy*'s production.

Though the type of data needed to empirically test the results of my model are not currently available to my knowledge (which justifies the need for the structural model developed in the paper), the model is able to replicate some empirical facts, especially the negative correlation between the average border delay and the real GDP per capita, and the input hoarding.[30] If anything, the estimated effects of the border delays here would rather be conservative than overestimated, because my model builds on many conservative assumptions. For example, the price of foreign inputs is likely higher than that of local inputs in reality. So assuming equal price for both as I do in the model, due to lack of data on price of imported inputs, is likely to bias the effects downwardly. Likewise, the omission of some additional costs directly related to border delays – including inventory keeping costs, depreciation during the process (my model takes into account only depreciation during production), and the effects of the delays on customers relationship (Hummels and Schaur, 2013; Djankov et al., 2010) – is also likely to bias the estimated effects downwardly. On the other hand, the predictions of my model lie well in the range one could expect from the literature. Djankov et al. (2010) estimated that a reduction of exports delays by just one day would increase exports by 1%. Considering that export is approximately 25% of GDP in Sub-Saharan Africa this amounts to 4% increase of GDP.[31] Moreover, they found that the effects are stronger in SSA. For example, if Uganda reduced its delay from 58 days to 27, exports would be expected to increase by 31% according to the authors.[32]

[30]To accuratly and empirically estimate the effects of border delays on macroeconomic outcomes like GDP, employment and investment, one would need panel data on the border delays and the portion of the aggregates related only to the formal economy as discussed in the previous paragraph. In addition to the need to control for key factors (the classic determinants of economic growth), one would need to control for time and country specific effects.

[31]See https://wits.worldbank.org/CountryProfile/en/SSF for exports as proportion of GDP in SSA.

[32]More directly related, Minor and Tsigas (2008) estimated the effect of import delays on GDP in many regions of the world using a computational general equilibrium (CGE) model. Their results show that 50% reduction of import

Table 2.3: Macroeconomic effects of the border delays in steady state per country

Country	Economy fundamentals				Gain (in%) from ↓ border delays to ≤ 1 week					
	Avg. delay	Foreign inputs (%)	Capital Proportion	Materials Proportion	Foreign inputs	Local inputs	Labor	Wage	Prod.	Cons.
Burundi	32.39	49.77	0.29	0.71	29.84	6.79	2.65	6.25	8.31	4.15
Mali	31.52	47.45	0.38	0.62	31.95	9.00	2.56	5.00	9.98	5.97
Chad	30.76	41.27	0.38	0.62	32.46	10.02	5.77	4.38	10.16	6.43
Togo	30.56	43.50	0.22	0.78	30.28	7.24	3.07	6.25	7.95	4.00
Tanzania	29.13	32.95	0.43	0.57	28.89	8.80	3.62	3.75	7.91	4.78
Niger	28.25	42.92	0.38	0.62	24.21	-2.11	0.01	4.38	4.22	1.98
Côte-d'ivoire	27.06	33.86	0.33	0.67	23.91	7.36	2.60	3.75	6.33	3.47
Mauritania	26.72	48.84	0.38	0.62	18.17	6.99	2.46	2.50	7.20	5.03
Cameroon	23.39	32.84	0.38	0.62	18.46	2.67	3.24	1.87	4.94	3.55
Kenya	22.52	27.94	0.37	0.63	21.43	7.59	1.63	2.50	5.89	3.59
Mozambique	21.58	28.40	0.39	0.61	13.37	3.67	1.99	2.50	2.20	0.44
Gambia	21.39	47.52	0.22	0.78	14.30	4.74	0.52	2.50	4.32	2.20
Capeverde	20.51	47.42	0.41	0.59	10.22	3.69	1.01	1.88	3.33	1.73
Eritrea	20.12	23.22	0.38	0.62	11.66	-0.45	-0.89	1.88	0.44	-0.43
Malawi	20.01	49.37	0.38	0.62	16.92	6.27	1.40	2.50	5.83	3.43
Ethiopia	19.49	17.79	0.47	0.53	10.73	1.94	-1.45	1.25	1.27	0.39
Uganda	19.44	13.56	0.33	0.67	11.81	2.89	1.41	0.63	2.76	2.13
Guinea	18.09	62.81	0.38	0.62	5.58	1.00	-0.62	1.87	1.16	-0.07
Senegal	17.93	18.53	0.31	0.69	16.15	0.72	0.21	1.88	1.38	0.32
Burkina-Faso	16.38	51.84	0.43	0.57	7.47	2.96	1.68	1.25	2.62	1.45
Madagascar	15.50	21.79	0.30	0.7	14.15	3.46	2.84	0.63	3.87	3.03
South Sudan	15.10	57.31	0.36	0.64	6.03	2.32	2.76	1.25	2.03	0.97
Ghana	14.79	47.74	0.42	0.58	6.32	2.23	2.32	1.25	1.75	0.67
Zambia	14.47	26.32	0.38	0.62	8.82	5.48	1.74	0.00	4.59	3.87
Rwanda	14.27	36.17	0.39	0.61	2.19	0.73	-1.58	0.63	0.46	0.10
Benin	14.06	52.70	0.23	0.77	6.09	2.64	2.03	1.25	2.21	1.15
Gabon	12.59	62.97	0.38	0.62	3.71	1.68	0.90	0.63	1.54	0.91

Continues on next page ...

Table 2.3 – continued from previous page

Country	Economy fundamentals				Gain (in%) from ↓ border delays to ≤ 1 week					
	Avg. delay	Foreign inputs (%)	Capital Proportion	Materials Proportion	Foreign inputs	Local inputs	Labor	Wage	Prod.	Cons.
Sierra Leone	12.48	30.07	0.38	0.62	3.53	1.45	0.12	0.63	0.87	0.37
CAR	11.86	53.66	0.38	0.62	2.77	1.98	2.69	0.00	1.88	1.64
mauritius	11.70	43.49	0.37	0.6277	5.98	2.56	1.84	0.00	3.08	2.60
Angola	11.43	27.36	0.57	0.43	1.15	-0.82	1.72	0.00	0.06	0.25
Zimbabwe	8.99	38.25	0.39	0.61	0.05	0.29	0.53	0.00	0.22	0.24
Nigeria	9.00	16.48	0.55	0.45	0.12	0.11	-2.75	0.00	0.10	0.10
Liberia	8.08	34.33	0.38	0.62	0.13	0.12	-2.54	0.00	0.12	0.13
somalia	6.85	50.59	0.38	0.62	-	-	-	-	-	-
Sudan	6.40	35.46	0.36	0.64	-	-	-	-	-	-
Namibia	5.44	23.21	0.33	0.67	-	-	-	-	-	-
Djibouti	5.09	62.02	0.38	0.62	-	-	-	-	-	-
Botswana	4.76	61.65	0.31	0.69	-	-	-	-	-	-
Lesotho	4.42	42.09	0.38	0.62	-	-	-	-	-	-
Eswatini	4.04	29.64	0.30	0.7	-	-	-	-	-	-
Min	4.04	13.56	0.22	0.43	0.05	-2.11	-2.75	0.00	0.06	-0.43
Max	32.39	62.97	0.57	0.78	32.46	10.02	5.77	6.25	10.16	6.43
Median	15.50	41.27	0.38	0.62	11.19	2.66	1.70	1.56	2.69	1.69
Mean	16.79	39.39	0.37	0.63	12.91	3.41	1.34	1.91	3.56	2.08

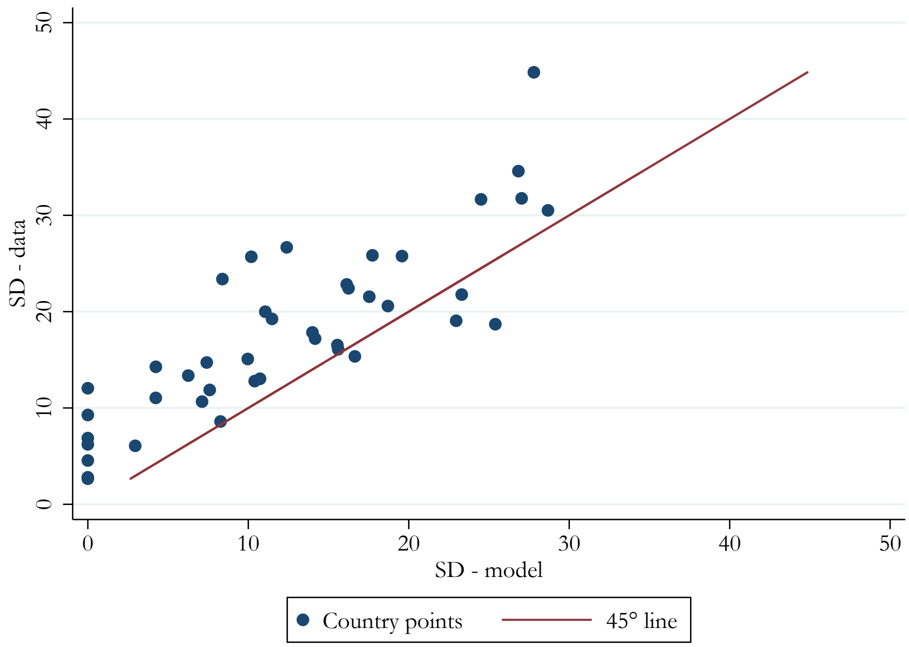

Figure 2.13: Standard deviations of delay in data and in the model.

Last, the model-induced standard deviation of delay is generally lower than the standard deviation of delay observed in the data (Figure 2.13). In other words, delay-related uncertainty is bigger in the data than in the model. This is likely to bias the estimated effects of delay downward. Nonetheless, uncertainty in the data is highly correlated with uncertainty in the model (correlation superior to 80%).

6 Conclusion

In this paper I show both analytically and quantitatively that foreign input delays at borders negatively affect firms and slow down economic growth. To mitigate the effects of border delays on input disruptions firms place higher investment order to build a buffer.

My analyses and findings suggest that the leaders of the Sub-Saharan African countries should take the appropriate measures to hasten clearance procedures at borders. Thereby, they can reduce investment costs for inputs importing firms and unleash economic growth. My recommendations echo the conclusion of many studies from the trade literature.[33] So to say, "modernizing border administration is, relatively speaking, less costly, less time consuming and politically easier than other interventions [...], border administration appears to be an appealing choice for countries wishing to implement speedy reforms; in other words, a *low-hanging fruit* for policymakers" (The World Economic Forum and The Global Alliance for Trade Facilitation, 2016).

delay (from 24.8 days to 12.4) in Sub-Saharan Africa would result in 4.2% increase in real GDP.

[33] E.g. Moïsé and Sorescu (2013); Montagnat-Rentier and Parent (2012); The World Economic Forum and The Global Alliance for Trade Facilitation (2016); Hoffman et al. (2016), etc.

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Article 3

Inputs delays, Firm Dynamics, and Misallocation in Sub-Saharan Africa *

Idossou Marius ADOM and Immo Schott†

Abstract.– We quantitatively analyze the macroeconomic consequences of border delays in Sub-Saharan Africa. Delays in imported capital goods lower aggregate output through factor misallocation and an insufficient number of firms that use foreign capital in production. Our model economy features heterogeneous firms that endogenously differ in the degree to which foreign capital goods are used. The model is calibrated to micro-level data from Sub-Saharan Africa. We find that the existing delays are akin to a 37% tax on imported capital goods. Reducing border delays can increase aggregate output by up to 14%. The gains are mainly due to a reallocation of economic activity towards more productive firms.

Keywords: Firm dynamics, heterogeneous firms, misallocation, border delays, Sub-Saharan Africa.

Individual contribution.– This article builds on the Article 2 of this thesis. It furthers the analysis of the macroeconomic impact of inputs delays at borders in a more general and a more complex model to account for many dimensions of firms heterogeneity. Specifically, the model economy features heterogeneous firms that endogenously differ in the degree to which they use foreign capital goods. The research of the paper is conducted in a very collaborative way. So our contribution each is transversal and approximately equal: 50/50.

*This paper is coauthored with my supervisor, Immo Schott. We have submitted it to the Revue of Economic Dynanmics and got Reject & Resubmit. We are currently revising the paper for resubmission soon.

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1 Introduction

In this paper we argue that border delays constitute a key obstacle for development. Using micro-data from Sub-Saharan Africa (SSA) we show that a large number of firms uses directly imported foreign capital goods in production. These foreign capital goods are often significantly delayed after arriving at a country's border. Figure 3.1 shows the average time it takes from the moment goods arrive at a point of entry until the time the goods can be claimed from customs. These delays are considerable and are several orders of magnitudes larger than in richer countries, where delays are often negligible.[2]

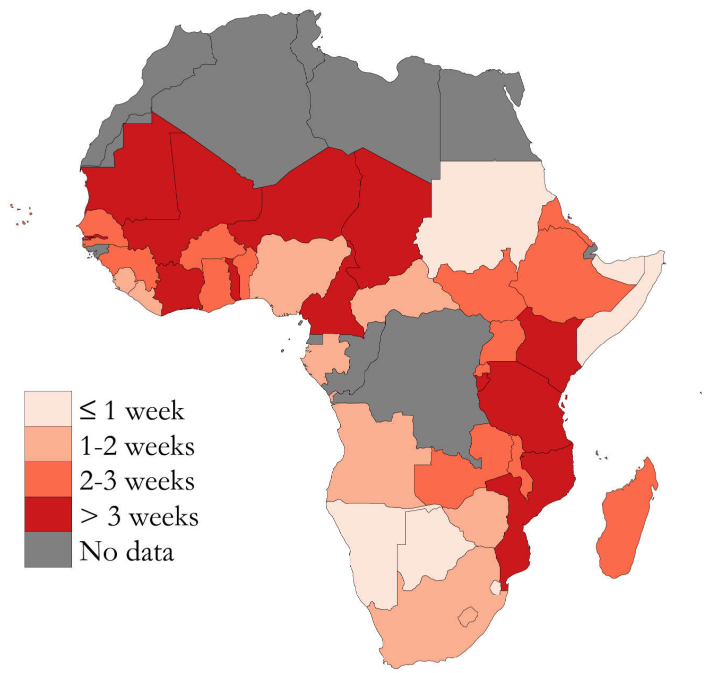

Figure 3.1: Border delays in Sub-Saharan Africa
Notes.– Darker colors represent longer average delays. Delays are measured as the time it takes from the moment that goods arrive at a point of entry until the goods can be claimed from customs. Source: Adom (2021) (see Article 2 in this thesis).

Delays at borders can result from a variety of sources, including customs and duty procedures, sanitary regulations, a lack of modern I.T., corruption, and the fact that border posts and customs offices are often physically separated (Barka, 2012). The resulting delays occur *after* a good arrives at a point of entry and are therefore distinct from factors such as poor roads, missing infrastructure, roadblocks, etc., which may delay the delivery of goods to or from a border point. To the best of our knowledge, this is the first paper to study the role of border delays in the context of a macroeconomic model with firm heterogeneity.

Border delays increase firms' costs of production for at least three reasons. First, there are

[2]Border delays across the world have increased due to the COVID-19 pandemic (see e.g. Bonadio, Huo, Levchenko, and Pandalai-Nayar (2021)).

opportunity costs that arise from allocating goods to storage. The second reason is depreciation, especially when production processes rely on speedy delivery. Finally, the uncertainty about delivery times creates a source of idiosyncratic risk that is specific to firms which are importing foreign capital goods. Importantly, we find that such firms are larger in terms of revenue and employment. Therefore, border delays create a distortion that appears to be positively correlated with firm productivity (Restuccia and Rogerson, 2008). In this paper we quantify the macroeconomic consequences of these border delays.

We develop a model of heterogeneous firms that differ in productivity and their production technology. Firms optimally choose whether to produce using only local inputs or to also import foreign capital goods. Importing foreign capital allows firms to scale up their operation, but they must then face the risk of border delays. Our quantitative results imply that removing border delays would increase aggregate output by 14%. The positive output effects come from two channels. First, through a better allocation of resources, away from small firms using only local inputs, towards larger, more productive firms that also use foreign inputs. Importing firms expand their scale of operation because the gains to using foreign imports increase when delays are reduced, both because of the shorter expected average delays, and because the uncertainty surrounding the delays is eliminated. Second, aggregate output increases because of a selection effect: a larger fraction of firms decides to upgrade their production technology and use foreign inputs in production. This increases output and labor demand.

Our paper contributes to the literature on the sources and consequences of factor misallocation. Persistent factor misallocation has been shown to lead to large losses in aggregate output and measured productivity (e.g. Hsieh and Klenow, 2009). Restuccia and Rogerson (2008) find that distortions which take the form of firm-specific "taxes" have the largest negative output effects when they are positively correlated with firm-level productivity. However, identifying real-world counterparts of such frictions is difficult. Often the implied output losses from directly observed distortions are small (*cf.* Restuccia and Rogerson, 2017).[3] In the context of developing countries, potential distortions include credit frictions, formality status, tax systems, and institutions.[4] We offer a new explanation, based on the prevalence of significant border delays. We find that these delays are a potential source of "correlated distortions" (Restuccia and Rogerson, 2008) because the affected firms are on average larger and likely to be more productive than firms that rely exclusively on local inputs. Our results imply that the existing border delays are akin to a 37% tax on foreign capital investment.

Our model builds on Hopenhayn and Rogerson (1993), to which we add two sources of heterogeneity. First, firms can endogenously upgrade their production technology to include local capital, and later foreign capital. Second, firms that choose to produce using foreign capital are

[3] Other recent examples include David and Venkateswaran (2019), Kaymak and Schott (2019), Bils, Klenow, and Ruane (2021), and Atkin and Donaldson (2021).

[4] Credit frictions are studied in Buera and Shin (2013), Midrigan and Xu (2014), Cole, Greenwood, and Sanchez (2016), and Itskhoki and Moll (2019). The literature on informality is summarized in La Porta and Shleifer (2014) and Ulyssea (2020). Tax systems are studied e.g. in Gordon and Li (2009). The role of institutions is summarized in Acemoglu, Johnson, and Robinson (2005).

subject to idiosyncratic delivery risk. With a given probability imported foreign capital goods are not available for production and an order remains outstanding, possibly to be delivered at a future date.

We contribute to the literature that links firms' technology adoption decisions to micro-level frictions, similar to Midrigan and Xu (2014).[5] Different from that paper, our mechanism does not include binding financial constraints for the most productive firms. Instead, we consider firms that choose to operate a technology which uses foreign inputs to be affected by border delays. Other related papers include Bhattacharya, Guner, and Ventura (2013) and Bento and Restuccia (2017). In those papers, firms are prevented from undertaking the optimal amount of productivity-enhancing investments by the presence of (unspecified) distortions.[6] Our framework includes a discrete choice between three types of technologies that either use only labor, labor and local capital, or, additionally, foreign inputs. Border delays only affect those firms that rely on foreign inputs. The technology adoption margin thus amplifies the effects of frictions, similar to other models of technology adoption. Our contribution is to show how this novel type of friction, significant border delays, leads to misallocation and output losses.

The delays in our model are conceptually different from standard time-to-build models (e.g. Kydland and Prescott (1982)), which typically assume a deterministic amount of time before investment projects are completed. In contrast, delays of imported capital goods are stochastic in our model, implying that firms cannot circumvent the friction by investing in advance, and further generating an additional negative effect through uncertainty (*cf.* Bloom (2009)).[7] Our model generates rich joint distributions of firm sizes, border delays, and outstanding orders across firms with different production technologies which are broadly in line with what we find in the Sub-Saharan African micro-data.

There is an empirical literature that studies the macroeconomic effects of delays. Those papers include Hummels and Schaur (2013), who use US imports data to show that each additional day a good spends in transit is equivalent to a tariff of up to 2.1%. Djankov, Freund, and Pham (2010) document cross-country heterogeneity in time delays for exporters and conclude that each additional day that a product is delayed prior to being shipped reduces trade by more than 1%. Vijil, Wagner, and Woldemichael (2019) find that in developing countries, border delays are linked to lower survival rates for internationally operating firms. We contribute to this literature by focusing on the consequences of input delays through the lens of a quantitative heterogeneous firm model that allows for the evaluation of a range of counter-factual equilibria.

The rest of the paper is organized as follows. We present our data in section 2 . Section 3 develops our heterogeneous firm model, which is used in our quantitative analysis of border delays

[5] An early example of endogenous technology adoption choices in the context of economic development is studied in Parente and Prescott (1994). Technology upgrading following the removal of an aggregate friction, trade liberalization, is studied in Bustos (2011),

[6] In an otherwise similar framework, Buera, Hopenhayn, Shin, and Trachter (2021) study the complementarity between firms' adoption decisions and find that this generates larger gains from removing micro-level distortions.

[7] In a related paper, Adom (2021) studies the effect of border delays in a model of ex-ante homogeneous firms. Meier (2020) studies stochastic time-to-build in U.S. business cycles due to supply chain disruptions.

in section 4 . Section 5 concludes.

2 Data

The data used in this paper comes from the most recent World Bank Enterprise Surveys (WBES). These surveys are representative of the universe of non-agricultural, formal, private sector firms for a large number of countries, especially developing countries. The data are deemed to be of high quality and have recently been used in related papers, including Ranasinghe and Restuccia (2018), Besley and Mueller (2018), and Atkin and Donaldson (2021). Our total sample consists of 10,830 firms across 42 Sub-Saharan African countries.[8]

Importantly for our purposes, the WBES not only provides information about firm size and revenue, but also includes, *inter alia*, three questions that determine to which degree firms use foreign inputs in production and to what extend they are affected by border delays. A complete list of the countries in our sample, the variables used, and the corresponding WBES survey questions can be found in Appendix 1 .

As a first step, we classify firms into three different *types* based on the degree to which foreign inputs are used in production. Firms which respond that no foreign inputs were used are classified as type 1 firms. Firms that use foreign inputs, but do not import these inputs directly, are classified as type 2 firms. Firms that use and directly import a positive amount of foreign inputs are defined as type 3 firms. The latter type is potentially subject to border delays.

Table 3.1 shows the distribution of firms in our sample. The resulting statistics are GDP-weighted averages across all countries in our sample. The table shows that almost 50% of firms do not use any foreign inputs in production. These *type 1* firms have fewer employees and are slightly younger compared to other firms. They make up about a third of total employment. We think of these firms as small, locally operating firms without a sophisticated production technology. An example from our dataset is a sewing shop in Lagos (Nigeria) with five employees.

Type 2 firms are older and larger than type 1 firms. They make up 27% of all firms, representing slightly under 20% of employment. Type 2 firms use foreign inputs, yet do not import them directly, but purchase them in local markets. We think of these firms as medium-scale production firms that produce output with a mix of different inputs. An example from our data is a 40-employee firm in Nairobi (Kenya) that produces plastic bags. This firm sources all of the required inputs locally, yet 50% of them are of foreign origin. To clearly delineate firm types and to render our estimates more conservative, we assume that there is no direct effect of border delays on type 2 firms.

Finally, *type 3* firms are the largest and oldest firms on average. The 90th percentile of type 3 firm sizes is 154 employees. These firms account for 23.4% of firms and have an over-proportional employment share of over 50%. We think of these firms as relatively large, internationally operating firms that use sophisticated production technologies. An example of a type 3 firm from our data

[8] The WBES from prior to 2009 do not include sampling weights, which is why we restrict our analysis to the most recent survey prior to 2020. We exclude South African data from the main part of our analysis because the survey was conducted in 2020 and 2021 and is thus potentially heavily affected by the global Covid-19 pandemic.

Table 3.1: Firms' characteristics by type

	Type 1	Type 2	Type 3	All
Uses inputs of foreign origin	No	Yes	Yes	–
Direct import of foreign inputs	No	No	Yes	–
Fraction of firms (in %)	48.6	27.0	24.3	100
Fraction of employment (in %)	30.5	18.8	50.6	100
Employment	23.3	27.7	89.3	37.3
Age (in years)	14.5	15.5	18.4	15.5
Share of foreign inputs	–	–	58.0	–

Notes.– Moments are GDP-weighted averages across countries. Source: World Bank Enterprise Survey, the 2010 World Bank national accounts data, and authors' calculations.

is a leather manufacturing company that employs 251 workers in Abidjan (Côte d'Ivoire). This company directly imports a fraction of its inputs and reports an average delay of 45 days for imported goods to clear the border.

To measure the importance of foreign capital, we calculate an average share of foreign inputs in production of 58%. Importantly, type 3 firms import foreign inputs directly and are therefore subject to border delays. Using the pertinent survey response allows us to construct the distribution over the border delays experienced by firms. The country-specific average delays were used to construct Figure 3.1. The overall GDP-weighted average delay is 13.8 days.

There is substantial heterogeneity in average border delays both across and within countries. This is shown in Figure 3.2, which ranks Sub-Saharan African countries from left to right by their 75th percentile in the delay distribution.[9] Average delays range from four days in Eswatini (formerly officially entitled Swaziland) to 32.4 days in Burundi. For comparison, average delays are under five days in Germany (included on the right of Figure 3.2 for reference), Sweden, and Spain, and about 6–7 days in Thailand.[10]

Figure 3.2 also shows that in many countries there is a high probability to experience a long delay of over 90 days. For example, Cameroon has an average delay of 23.4 days, yet 10% of all orders experienced a delay of at least 90 days.[11]

We now develop our economic model to study the macroeconomic effects of border delays.

[9]Not all countries are surveyed in the same year, but country-averages are fairly stable over time for countries where two surveys are available. For example. the average border delay in Cameroon was 23.9 days in 2009 and 23.4 days in 2016.

[10]We show a distributional plot for a number of richer economies in Figure C.1 in Appendix 1 .

[11]These findings are confirmed by a large number of case studies. For example, Raballand, Refas, Beuran, and Isik (2018) document high average amounts of time that cargo spends within African ports as well as the frequent occurrence of extremely long delays. United Nations (2010) estimate delays in crossing borders for products in Sub-Saharan Africa to be the lengthiest in the world. According to Portugal-Perez and Wilson (2009), the number of import procedures in Sub-Saharan Africa is among the highest in the world. The World Bank (2012) finds that an average customs transaction in Africa involves 20 to 30 different parties, 40 documents, 200 data elements (30 of which are repeated at least 30 times) and the rekeying of 60 to 70 per cent of all data at least once.

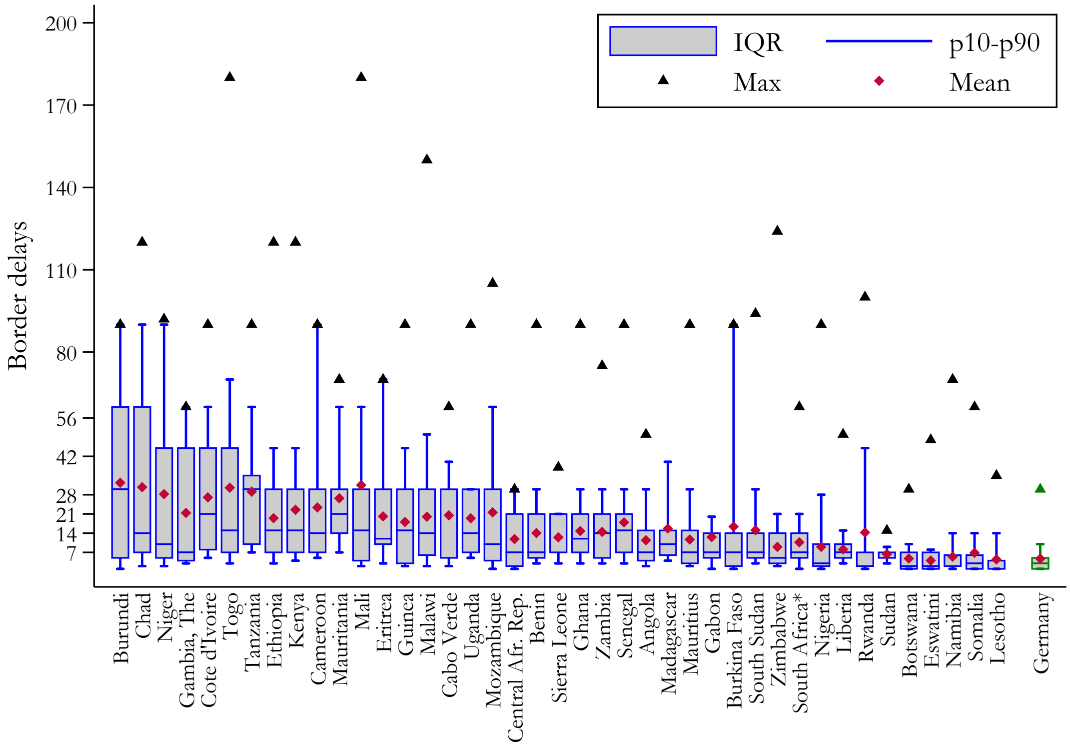

Figure 3.2: Border delays in Sub-Saharan Africa

Notes.– The figure shows country-specific distributions of border delays in days. The box plots cover the 25th to 75th percentiles of delays. Medians are indicated by the horizontal bar. The lines extending from the boxes show the 10th and 90th percentiles. Averages are shown as red diamonds. The black triangles show the maximum delays. Minimum delays were zero in all cases. Source: World Bank Enterprise Survey and authors' calculations. South Africa is shown here for purposes of comparison but is excluded from the calculation of cross-country moments because of the survey year 2020/21.

3 Model

Time is discrete and the horizon is infinite. A model period corresponds to one week.[12] The economy consists of a mass of heterogeneous firms and a representative household. At time t a positive mass of price-taking firms produces a homogenous output good using a combination of labor and capital. The price of the output good serves as the numéraire. Firms can accumulate foreign and local capital. All capital depreciates at rate $\delta \in (0, 1)$. Future profits are discounted with $\rho \in (0, 1)$.

While labor can only be hired on a domestic spot market at the wage rate w_t, capital can either be acquired locally or directly imported from international markets. The benefit of using foreign capital is that it complements domestic inputs in production. The downside is that this exposes firms to delivery risk.

[12]Because average border delays are in the order of two weeks, choosing a model period appropriately is important to gauge the effect of delays. Similar to the labor search literature, a model period must be chosen such that the probability of success (in this case a delivery) is below unity.

There are three firm *types*, indexed by $j = \{1, 2, 3\}$. Firms start operating as type 1, but can choose to upgrade. Following the definitions used to analyze the data, firm types differ in the complexity of their production technology. Production of the final good is given by

$$y_t = \mu_j \varepsilon_t F^j(n_t, k_t), \tag{3.1}$$

where $F^j(\cdot)$ denotes the production function of a type j firm, and μ_j is a productivity shifter. The productivity parameter ε_t is idiosyncratic and follows a Markov chain, $\varepsilon \in \{\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_K\}$, where $\Pr(\varepsilon' = \varepsilon_k | \varepsilon = \varepsilon_i) \equiv \pi_{ik} \geq 0$ and $\sum_{k=1}^{K} \pi_{ik} = 1$ for each $i = 1, \ldots, K$.

There exists a large mass of potential entrants, of whom a constant mass $M > 0$ enters the economy each period by paying an entry cost $c_e \geq 0$. The initial productivity level ε_0 is drawn from the stationary distribution π_0. The subsequent evolution of productivity is governed by π_{ik}. A fraction x of incumbent firms exogenously exits the economy at the end of a period. Exiting firms cannot re-enter the market at a later period. Upon exit, a firm's remaining capital stock is liquidated, and a fraction θ of it can be distributed to its owners along with any income generated prior to exit. Outstanding foreign orders and a fraction $(1-\theta)$ of current capital are lost upon exit.

3 .1 Firm types

There are three firm *types*. Firms enter the economy as type 1. Upon paying a fixed cost, denoted in terms of the consumption good, the firm can be upgraded to the next type, as explained below.

A type 1 firm uses labor as the only input in production, so that $F^1(n_t, k_t) = n_t^{\zeta}$, with $\zeta \in (0, 1)$. Type 2 and type 3 firms produce output using labor and capital with the production function $F^j(n_t, k_t) = n_t^{\beta} k_t^{\alpha}$ for $j \in \{2, 3\}$, with $\alpha \in (0, 1)$ and $\alpha + \beta = \zeta$.

The difference between type 2 firms and type 3 firms is that type 2 firms use only local capital, denoted as k_l, and no foreign capital. Therefore, $k_t = k_{lt}$ for type 2 firms. The accumulation of local capital is standard and follows the law of motion

$$k_{l,t+1} = k_{lt} \cdot (1 - \delta) + i_{lt}. \tag{3.2}$$

For type 3 firms the effective amount of capital used in production, k_t, is given by a combination of local (l) and foreign (f) capital:

$$k_t(k_{lt}, k_{ft}) = \left[\phi^{\frac{1}{\sigma}} k_{lt}^{\frac{\sigma-1}{\sigma}} + (1 - \phi)^{\frac{1}{\sigma}} k_{ft}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{3.3}$$

The parameter ϕ denotes a share parameter of local inputs, while σ determines the elasticity of substitution between local and foreign inputs. Foreign and domestic inputs are gross substitutes if $\sigma > 1$ and gross complements if $\sigma < 1$.

Investment into foreign capital is denoted as i_{ft}. Different from local capital, foreign capital needs to be ordered from international markets and because of possible delays at the border, these foreign investments have an associated delivery risk. This implies that a positive investment $i_{ft} > 0$ adds to a firm's stock of outstanding orders, which may or may not be delivered prior to the next production cycle. The total stock of outstanding orders after investment is denoted $\tilde{o}_{f,t+1}$, and is given by the sum of previously undelivered orders and new positive investment into foreign capital, denoted as i^+_{ft}:

$$\tilde{o}_{f,t+1} = o_{ft} + i^+_{ft} \tag{3.4}$$

This formulation implies that previously placed orders cannot be canceled.

To capture the idea that outstanding orders may be delayed at the border, we denote the probability that outstanding orders $\tilde{o}_{f,t+1}$ are delivered as ψ. The law of motion of foreign capital is given then by:

$$k_{f,t+1} = \begin{cases} k_{ft} \cdot (1-\delta) + i^-_{ft} + \tilde{o}_{f,t+1} & \text{with probability } \psi \\ k_{ft} \cdot (1-\delta) + i^-_{ft} & \text{with probability } 1-\psi \end{cases} \tag{3.5}$$

This equation says that outstanding orders only add to next period's foreign capital with probability ψ. Existing foreign capital can be liquidated with certainty. Negative foreign capital investments $i_{ft} < 0$ are denoted as i^-_{ft}.

Finally, the law of motion of outstanding orders of foreign capital at the beginning of the next period is:

$$o_{f,t+1} = \begin{cases} 0, & \text{with probability } \psi \\ \tilde{o}_{f,t+1} & \text{with probability } 1-\psi \end{cases} \tag{3.6}$$

This implies that an outstanding order is either delayed or fully delivered, i.e., there is no partial delivery.

To fix ideas, consider the special case of no delays, implying $\psi = 1$. From (3.6) outstanding orders prior to investment would always be zero and the accumulation of foreign capital in (3.5) would follow the same standard law of motion as local capital.

While firms start out as type 1, upon paying a fixed cost ξ_1, they can upgrade their production technology, i.e., become a type 2 firm that uses local capital in addition to labor. Every period, firms draw a realization of ξ_1 from a time-invariant uniform distribution $G_1(\xi_1)$, common across plants, as in Thomas (2002). The upper bound of the distribution is denoted Ξ_1. If the cost is paid, a firm can immediately start investing in local capital and becomes a type 2 firm next period. We interpret the fixed cost ξ_1 as a technology adoption cost which represents fundamental changes in a firm's scope, customer base, and production technology.

Similarly, type 2 firms can, upon paying a fixed cost ξ_2, upgrade to type 3 firms. This enables them to start importing foreign inputs. Draws of ξ_2 are taken from the uniform distribution $G_2(\xi_2)$ with upper bound Ξ_2. If the cost is paid, the firm may immediately start importing foreign inputs and becomes a type 3 firm next period. The fixed cost can be interpreted the costs of establishing international supply chains. Type 3 firms do not draw a fixed cost and cannot be downgraded to

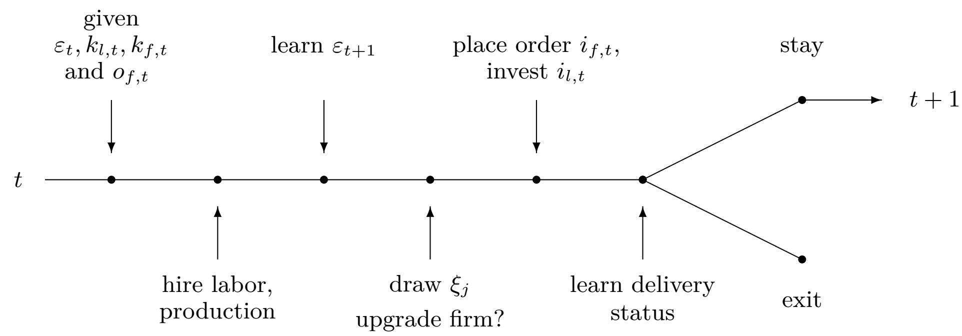

Figure 3.3: Timing

types 1 or 2.

The timing is shown in Figure 3.3. At the beginning of a period t, a firm's state consists of its current idiosyncratic productivity level ε_t, as well as its current levels of local and foreign capital. In addition, the state also includes the amount of outstanding, previously undelivered, orders of foreign capital, o_{ft}.[13] These stocks are determined through past accumulation decisions and histories of idiosyncratic realizations of delivery shocks.

Given a firm's state, it hires labor on a local spot market and produces output. After production, a firm learns its future productivity level. Each *type 1* and *type 2* firm draws a realization of the fixed cost required to upgrade the firm to the next type. If a current type 1 firm pays the fixed cost ξ_1, the firm becomes a type 2 firm next period. Such a firm may immediately begin investing in local capital. For current type 2 firms, paying the fixed cost ξ_2 allows the firm to immediately begin investing in foreign capital and start the next period as a type 3 firm.

Knowing its future type, firms make investment decisions into local and/or foreign capital. At the end of a period, firms learn about the status of their orders in foreign capital. If firms do not exogenously exit the economy, they continue operation in period $t+1$.

3 .2 Firm problem

We now define the maximization problem of the firm recursively. Time subscripts are omitted in this formulation. Primes indicate future variables. A firm's type is $j \in \{1, 2, 3\}$.

Type 1 firm. The state vector of type 1 firms is given by $s_1 = \{\varepsilon, \xi_1\}$. First we define the beginning-of-period expected value of a firm. At this point, the firm knows its current value of ε, but has not yet learned the realization of its fixed cost draw.

$$V^1(\varepsilon) = \max_n \left(\mu_1 \varepsilon n^\zeta - wn\right) + \int_0^{\Xi_1} \sum_{k=1}^{K} \pi_{ik} \tilde{V}^1(\varepsilon_k, \xi_1) dG_1(\xi_1) \tag{3.7}$$

[13]For type 2 firms, $k_{ft} = o_{ft} = 0$. For type 1 firms, additionally $k_{lt} = 0$.

Given ε and the equilibrium wage rate w the firm chooses current employment n. The function $\tilde{V}^1$ is the end-of-period continuation value when future productivity and the fixed cost draw are realized. It is given by

$$\tilde{V}^1(\varepsilon, \xi_1) = \max\Bigg\{ \underbrace{(1-x)\rho V^1(\varepsilon)}_{\text{do not upgrade}} , \underbrace{-\xi_1 + \max_{i_l}\Big(-i_l + (1-x)\rho V^2(\varepsilon, k_l') + x\rho V_x^2(k_l')\Big)}_{\text{upgrade \& invest}} \Bigg\}\Bigg). \tag{3.8}$$

At the end of the period, the firm chooses whether to upgrade to a type 2 firm. The value of upgrading is given by the second term in the binary maximum choice in (3.8). The firm incurs the fixed cost ξ_1 and then makes a (local) capital investment i_l. The law of motion for local capital is given by (3.2).[14] In case of exogenous exit after upgrading, the value is given by $V_x^2(k_l) = \theta k_l$, i.e., the firm recuperates a fraction θ of the invested capital and then ceases operating.[15] We denote as $n^1(\varepsilon)$ and $\hat{i}_l^1(\varepsilon)$ the policy functions for employment and a potential initial investment in local capital.

From (3.8) a firm will pay the fixed cost ξ_1 and upgrade only if the value of doing so exceeds the continuation value as a type 1 firm. The upgrading decision is then governed by a threshold rule and will occur if ξ_1 is below some ε-specific value $\bar{\xi}_1$. Let $\tilde{\xi}_1$ denote the level of ξ_1 which makes a plant indifferent between upgrading or not:

$$(1-x)\rho V^1(\varepsilon) = -\tilde{\xi}_1 + \max_{i_l}\Big(-i_l + (1-x)\rho V^2(\varepsilon, k_l') + x\rho V_x^2(k_l')\Big) \tag{3.9}$$

This defines the threshold value as $\bar{\xi}_1(\varepsilon) \equiv \min\{\Xi_1, \max\{0, \tilde{\xi}_1\}\}$ and ensures that it is within the support of the the distribution. Firms which draw $\xi_1 < \bar{\xi}_1(\varepsilon)$ will upgrade to type 2 firms. The fraction of upgrading firms with productivity ε is given by $G_1(\bar{\xi}_1(\varepsilon))$. The upgrading probability is increasing in productivity ε.

Type 2 firm. The state vector of type 2 firms is given by $s_2 = \{\varepsilon, k_l, \xi_2\}$. Analogously to type 1 firms, the beginning-of-period expected value of a type 2 firm is given by

$$V^2(\varepsilon, k_l) = \max_n \Big(\mu_2 \varepsilon\ F^2(n, k_l) - wn\Big) + \int_0^{\Xi_2} \sum_{k=1}^{K} \pi_{ik} \tilde{V}^2(\varepsilon_k, k_l, \xi_2) dG_2(\xi_2). \tag{3.10}$$

The firm maximizes static profits by choosing n. At the end of the period, after learning future productivity and the fixed cost ξ_2, the firm makes an investment decision and decides whether to

[14] The value of a type 2 firm is formally defined below.
[15] The value of exit for a type 1 firm is zero because such a firm has no capital.

upgrade the firm:

$$\tilde{V}^2(\varepsilon, k_l, \xi_2) = \max\Bigg\{ \underbrace{\max_{i_l}\Big(-i_l + (1-x)\rho V^2(\varepsilon, k_l') + x\rho V_x^2(k_l')\Big)}_{\text{do not upgrade}},$$

$$\underbrace{-\xi_2 + \max_{i_l, i_f}\Big(-i_l - i_f + (1-x)\rho \mathbb{E}_\psi V^3(\varepsilon, k_l', k_f', o_f') + x\rho \mathbb{E}_\psi V_x^3(k_l', k_f')\Big)}_{\text{upgrade \& invest}} \Bigg\} \quad (3.11)$$

If the firm does not upgrade to a type 3 firm, it only makes a local capital investment choice. The second row of (3.11) says that when the firm decides to upgrade the firm, it makes both a local and a foreign capital investment. Conditional on survival, the firm becomes a type 3 firm next period. Upon exit, it receives the value $V_x^3(k_l, k_f) = \theta(k_l + k_f)$. For an upgrading firm, both $V^3(\cdot)$ and $V_x^3(\cdot)$ depend on the probability that the foreign capital investment is delivered next period. If the investment is not delayed, it becomes the future level of foreign capital. If the investment is delayed, it increases instead the future stock of outstanding orders. The associated expectation operator is denoted as $\mathbb{E}_\psi$. We denote as $n^2(\varepsilon, k_l)$ and $i_l^2(\varepsilon, k_l)$ the policy functions for employment and investment in local capital. The policy functions for an upgrading firm are denoted $\hat{i}_l^2(\varepsilon, k_l)$ and $\hat{i}_f^2(\varepsilon, k_l)$.[16]

As for type 1 firms, there exists a state-specific threshold value of $\bar{\xi}_2$ such that firms which draw $\xi_2 < \bar{\xi}_2(\varepsilon, k_l)$ will upgrade to type 3 firms. The fraction of upgrading firms in state (ε, k_l) is given by $G_2(\bar{\xi}_2(\varepsilon, k_l))$. The upgrading probability is increasing in productivity ε.

Type 3 firm. For type 3 firms the state vector consists of $s_3 = \{\varepsilon, k_l, k_f, o_f\}$. Different from the other firm types, a type 3 firm can no longer be upgraded and therefore does not face a discrete choice problem. At the beginning of a period a type 3 firm has learned whether any past investments have been delayed, i.e., it knows the amount of outstanding orders, o_f. The value is given by

$$V^3(\varepsilon, k_l, k_f, o_f) = \max_{n, i_l, i_f^+, i_f^-} \Bigg\{ \mu_3 \varepsilon F^3(n, k_l, k_f) - wn - i_l - i_f^+ - \theta i_f^-$$

$$+ (1-x)\rho \cdot \sum_{k=1}^{K} \pi_{ik} \mathbb{E}_\psi V^3(\varepsilon_k, k_l', k_f', o_f') + x \cdot \rho \mathbb{E}_\psi V_x^3(k_l', k_f') \Bigg\}. \quad (3.12)$$

From (3.12), this firm begins a period with a given level of idiosyncratic productivity, levels of local and foreign capital in the firm, and a level of outstanding, previously undelivered orders of foreign capital. The firm solves a static labor optimization problem and invests into future capital. Existing capital in place can be sold at a markdown of $\theta < 1$, reflecting capital specificity.

The future stock of foreign capital k_f' is subject to delivery risk. In case of exogenous exit, the firm is liquidated and a fraction θ of the installed capital is sold at the beginning of the following period, captured by the value V_x^3. The policy functions for labor, and local and foreign capital

[16] If the initial order is delivered, the firm has future foreign capital $k_f' = \hat{i}_f^2(\cdot)$ and $o_f' = 0$. If the order is not delivered $k_f' = 0$ and $o_f' = \hat{i}_f^2(\cdot)$.

investment are given by $n^3(\varepsilon, k_l, k_f, o_f)$, $i_l^3(\varepsilon, k_l, k_f, o_f)$, and $i_f^3(\varepsilon, k_l, k_f, o_f)$. The laws of motion for foreign capital and outstanding orders (3.5) and (3.6) imply two distinct possible future realizations of these variables, depending on whether outstanding orders are delayed. We denote future foreign capital and outstanding orders in case of delivery as k_{f1} and o_{f1} and in case of no delivery as k_{f0} and o_{f0}.[17]

3 .3 Entrant's problem

New entrants start as type 1 firms. A potential entrant starts its operations if the value of entry exceeds the entry cost: $V^e \geq c_e$. The value of entry is the expected beginning-of-period value of a type 1 firm.

$$V^e = \sum_{k=1}^{K} \pi_0(\varepsilon_k) V^1(\varepsilon_k) \tag{3.13}$$

This formulation implies that upon paying c_e, entrants' initial productivity level is revealed. The entry costs reflect the cost of identifying a business idea, a target market, as well as all costs associated to setting up a business.

3 .4 Distribution of firms

Let $\mathbf{\Gamma}^j(s_j)$ denote the beginning-of-period distribution of incumbent type j firms over the relevant firm states s_j for $j = \{1, 2, 3\}$. With $\mathcal{M}$ denoting the mass of entrants, the law of motion for the distribution of type 1 firms is given by

$$\mathbf{\Gamma}^{1\prime}(\varepsilon_k) = \sum_{i=1}^{K} (1-x)(1 - G_1(\bar{\xi}_1(\varepsilon_i)))\pi_{ik} \mathbf{\Gamma}^1(\varepsilon_i) + \pi_0(\varepsilon_k)\mathcal{M}. \tag{3.14}$$

The first term represents the evolution of current type 1 firms that do not exit and do not upgrade. The second term represents entering firms.

The law of motion for incumbent type 2 firms is

$$\mathbf{\Gamma}^{2\prime}(\varepsilon_k, k_l') = \sum_{i=1}^{K} (1-x)(1 - G_2(\bar{\xi}_2(\varepsilon_i, k_l)))\mathcal{I}_2(\varepsilon_i, k_l)\pi_{ik}\mathbf{\Gamma}^2(\varepsilon_i, k_l) + \sum_{i=1}^{K} G_1(\bar{\xi}_1(\varepsilon_i))\mathcal{I}_1(\varepsilon_i)\pi_{ik}\mathbf{\Gamma}^1(\varepsilon_i). \tag{3.15}$$

The first term represents current type 2 firms that do not exit and do not upgrade. The indicator function $\mathcal{I}_2(\varepsilon, k_l) = 1$ if $k_l' = (1-\delta)k_l + i_l^2(\varepsilon, k_l)$. The second term represents current type 1 firms that upgrade to type 2 firms. The indicator function $\mathcal{I}_1(\varepsilon) = 1$ if $k_l' = \hat{i}_l^1(\varepsilon)$.

[17] More precisely, we have that $k_{f1} = k_f \cdot (1-\delta) + i_f^3(\varepsilon, k_l, k_f, o_f) \cdot (i_f^3(\varepsilon, k_l, k_f, o_f) < 0) + \tilde{o}_f'$, and $o_{f1} = 0$, while $k_{f0} = k_f \cdot (1-\delta) + i_f^3(\varepsilon, k_l, k_f, o_f) \cdot (i_f^3(\varepsilon, k_l, k_f, o_f) < 0)$, and $o_{f1} = \tilde{o}_f'$.

Finally, the law of motion for incumbent type 3 firms is

$$\begin{aligned}\mathbf{\Gamma}^{3\prime}(\varepsilon_k, k_l', k_f', o_f') &= (1-x)\sum_{i=1}^{K}\mathcal{I}(\varepsilon_i, k_l, k_f, o_f)\pi_{ik}\mathbf{\Gamma}^3(\varepsilon_i, k_l, k_f, o_f) \\ &\quad + \sum_{i=1}^{K} G_2(\bar{\xi}_2(\varepsilon_i, k_l))\mathcal{I}_3(\varepsilon_i, k_l)\pi_{ik}\mathbf{\Gamma}^2(\varepsilon_i, k_l). \end{aligned} \tag{3.16}$$

The first term represents the current type 3 firms that do not exit. The indicator function $\mathcal{I}(\varepsilon, k_l, k_f, o_f)$ takes the value ψ if $k_l' = (1-\delta)k_l + i_l^3(\varepsilon, k_l, k_f, o_f)$, $k_f' = k_{f1}$, and $o_f' = o_{f1}$. It takes the value $1-\psi$ if $k_l' = (1-\delta)k_l + i_l^3(\varepsilon, k_l, k_f, o_f)$, $k_f' = k_{f0}$, and $o_f' = o_{f0}$. Using a law of large numbers, we assume that orders for a fraction $1-\psi$ of firms are delayed.

The second term in (3.16) represents current type 2 firms that upgrade to type 3 firms. The indicator function $\mathcal{I}_3(\varepsilon, k_l)$ takes the value ψ if $k_l' = (1-\delta)k_l + \hat{i}_l^2(\varepsilon, k_l)$, $k_f' = \hat{i}_f^2(\varepsilon, k_l)$, and $o_f' = 0$. It takes the value $1-\psi$ if $k_l' = (1-\delta)k_l + \hat{i}_l^2(\varepsilon, k_l)$, $k_f' = 0$, and $o_f' = \hat{i}_f^2(\varepsilon, k_l)$.

In the stationary equilibrium the distributions $\mathbf{\Gamma}^j(s_j)$ for $j = \{1, 2, 3\}$ will be constant over time. With $x > 0$ the mappings defined above have unique invariant distributions associated with them. Additionally, the distributions are linear in the mass of entrants $\mathcal{M}$.

3 .5 Households

The representative household derives utility from consumption and leisure, with $U(C, N) = \log(C) - \frac{\lambda}{1+\frac{1}{\chi}} \cdot N^{1+\frac{1}{\chi}}$. The term λ determines the disutility from hours worked, while χ is the inverse Frisch elasticity. Consumption is given by total disposable income, which consists of labor earnings plus dividends: $C^d = D + w \cdot N^s$. Dividends D are the aggregate profits that are distributed from firms to households. The investment decision is handled by firms.

3 .6 Competitive Equilibrium

A stationary recursive competitive equilibrium consists of type-specific beginning-of-period value functions $V^1(\varepsilon)$, $V^2(\varepsilon, k_l)$, $V^3(\varepsilon, k_l, k_f, o_f)$, a value of entry V^e, type-specific policy functions for labor, local, and foreign capital, cutoff values for upgrading $\bar{\xi}_1$ and $\bar{\xi}_2$, a wage rate w, distributions $\mathbf{\Gamma}^j$ for $j = \{1, 2, 3\}$, and a measure of entrants $\mathcal{M}$ such that:

1. The household optimizes: $N^s = \left(\frac{w}{\lambda \cdot C}\right)^{1/\chi}$.
2. For $j = \{1, 2, 3\}$, the value function V^j together with the associated policy functions solves the respective incumbent firm's problem.
3. The free entry condition holds: $V^e = c_e$.
4. The type-specific distributions over incumbent firms are stationary: $\mathbf{\Gamma}'^j = \mathbf{\Gamma}^j$ for $j = \{1, 2, 3\}$.
5. Markets clear:

$$\sum_{j=1}^{3} \int n^j(s_j) d\mathbf{\Gamma}^j \cdot \mathcal{M} = N^s = N^* \text{ and } C = Y - I^k - I^\xi - \mathcal{M} \cdot c_e$$

The last equation gives the resource constraint of the economy. Total output is $Y = \sum_{j=1}^{3} \int y(s_j) d\mathbf{\Gamma}^j \mathcal{M}$. Resources used for capital investment are given by I^k, which includes local and foreign capital investments by all firms, net of non-depreciated capital and the scrap value of exiting firms. Resources used for upgrading firms are $I^\xi = \frac{1}{2}\left[\frac{\bar{\xi}_1(\varepsilon)^2}{\Xi_1}\mathbf{\Gamma}^1 + \frac{\bar{\xi}_2(\varepsilon)^2}{\Xi_2}\mathbf{\Gamma}^2\right]$ The last term denotes the total resources spent on firm entry.[18]

4 Quantitative analysis of border delays

In this section, we use a quantitative version of the model developed in the previous section in order to assess the effects of border delays in Sub-Saharan African countries. We calibrate the model to match the firm size and employment distributions from African data, targeting average border delays of about 14 days. We then compare this economy to a counterfactual one in which border delays are eliminated. This allows us to quantify the impact of border delays on macroeconomic outcomes.

4 .1 Computational strategy

To solve our model numerically, we use value function iteration with interpolation. The equilibrium wage is found via bisection.

To reduce the number of necessary state variables, we exploit the fact that local capital is not subject to adjustment costs and adopt an equivalent but computationally more convenient formulation. The algorithm to solve the model defines a computational period to begin after future productivity is realized, but before the investment decisions are made. By adding non-depreciated local capital to current profits, we assume that the entire stock of local capital is repurchased every period. This implies that the policy functions for labor, as well as local capital can be derived analytically. The key challenge of the computational solution then consists in solving for the policy functions for foreign capital investments, which influences the evolution of the two endogenous state variables, foreign capital, and outstanding orders. Appendix 2 shows the modified firm problem in more detail.

4 .2 Calibration

A number of parameters are preset, while others are calibrated to match data moments. The parameters set outside the model are shown in Table 3.2. We target an annual real rate of return of 5%, implying $\rho = 0.95$. Following Restuccia and Rogerson (2008), we set the span-of-control parameter ζ to 0.85, and split it into α and β according to their income shares of 2/3 and 1/3. implying $\alpha = 0.283$ and $\beta = 0.567$. The annual depreciation rate is set to 10%. From the WBES data we compute an average foreign capital share in production of type 3 firms of about 60%. This

[18] These equations imply that dividends paid to households are given by $D = Y - w \cdot N^* - I^k - I^\xi - \mathcal{M} \cdot c_e$.

implies $\phi = 0.4$ in (3.3), the equation that defines effective capital. The elasticity of substitution between local and foreign capital is set to 0.5, following Chang (1995) and Boehm, Flaaen, and Pandalai-Nayar (2019). The exogenous exit rate is set to 10% annually. The recovery value of capital is $\theta = 0.9$.[19] We set the inverse Frisch elasticity to 1.2, which is in the range suggested by Chetty, Guren, Manoli, and Weber (2011). The value of λ is set to generate a labor supply of 1 in the baseline economy. Without loss of generality, we normalize the wage in the benchmark economy to 1, which pins down the entry cost c_e from the free-entry condition (3.13). A key parameter is the average delay of foreign capital investments. We compute an average delay for imported foreign capital goods of 13.8 days in the WBES data. This implies a weekly delivery probability of $\psi = 0.41$.

Table 3.2: Externally calibrated parameters

Parameter	Value	Meaning
ρ	0.95	Discount factor (annual)
ζ	0.85	Curvature of production function
α	0.28	Capital income share
β	0.57	Labor income share
δ	0.10	Depreciation rate (annual)
λ	0.86	Household disutility of labor
χ	1.2	Inverse Frisch elasticity
ψ	0.41	Average import delay of 13.8 days
ϕ	0.40	Local capital share in production of type 3 firms
σ	0.50	Elasticity of substitution between capital types
x	0.10	Exogenous exit rate (annual)
θ	0.90	Recovery value of capital
c_e	0.10	Entry cost

The six remaining parameters $\Theta = \{\mu_1, \mu_2, \Xi_1, \Xi_2, \rho_\varepsilon, \sigma_\varepsilon\}$ are found by matching six data moments that are informative about the joint distributions of firms, employment, and firm types. The parameters were chosen to minimize the average percentage difference between data and model moments. The calibrated parameter values are shown in Table 3.3, together with a comparison between data and model moments. The parameters are jointly identified, yet we briefly describe the intuition behind the identification and our choice of data moments.

The first two parameters determine the relative productivity of type 1 and type 2 firms. These parameters directly impact the average firm size and are used to match the fraction of total employment in firms of the respective type. The upper bounds of the distributions of upgrading costs are key in determining the distribution of firms across types. We therefore identify these parameters from the fraction of type 1 and type 2 firms in the data. The idiosyncratic productivity parame-

[19] We present robustness exercises with respect to these parameter choices in Appendix 3 .

ters ρ_ε and σ_ε shape the firm size and employment distributions, as well as the concentration of employment. The data is organized in employment bins. We match the fraction of firms in the largest size bin (100+ employees) as well as the employment share of small firms, defined as firms with less than 20 employees.

Table 3.3: Internally calibrated parameters

Parameter	Value	Moment (in %)	Data	Model
μ_1	2.22	Employment share of type 1 firms	30.52	31.02
μ_2	0.78	Employment share of type 2 firms	18.83	18.83
Ξ_1	15.15	Fraction of type 1 firms	48.64	47.72
Ξ_2	35.83	Fraction of type 2 firms	27.04	26.70
ρ_ε	0.88	Fraction of large firms	6.67	7.50
σ_ε	0.07	Employment share of small firms	22.14	21.98

Table 3.3 shows that the model matches the data moments very well, both unconditionally and conditional on firm type. From the table, although the distributions of the number of firms and of total employment by firm types are close to the data, one shortcoming is that the model generates a too high share of large firms, and an unconditional employment share of small firms that is slightly below its data counterpart.

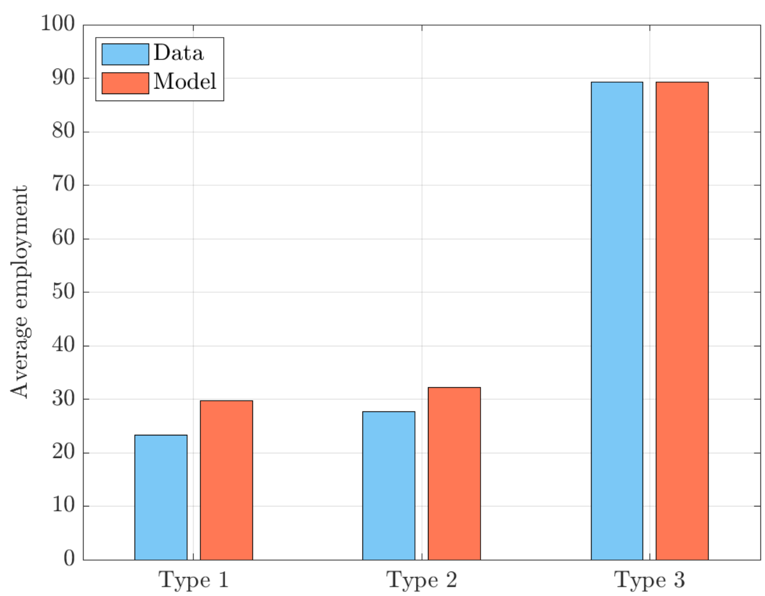

Figure 3.4: Untargeted moments: Average employment by firm type

Nevertheless, the model is successful in replicating a number of untargeted moments. Figure 3.4 shows average firm size by type, which is well matched by the model. Figures 3.5 and 3.6 show the distributions of firms and employment by firm type and jointly for all firms. A key data feature that is replicated by the calibrated model is that most firms are small, while employment is concentrated among large firms: Roughly 75% of all type 1 and 2 firms have fewer than 20 employees, while more than 60% of total employment among type 1 and 2 firms is concentrated in large firms. The fraction of large type 3 firms is significantly higher, as is the employment share of large type 3 firms. Importantly, the model is able to generate both large type 1 firms and small type 3 firms. However, it does not generate as many small type 3 firms as we see in the data.

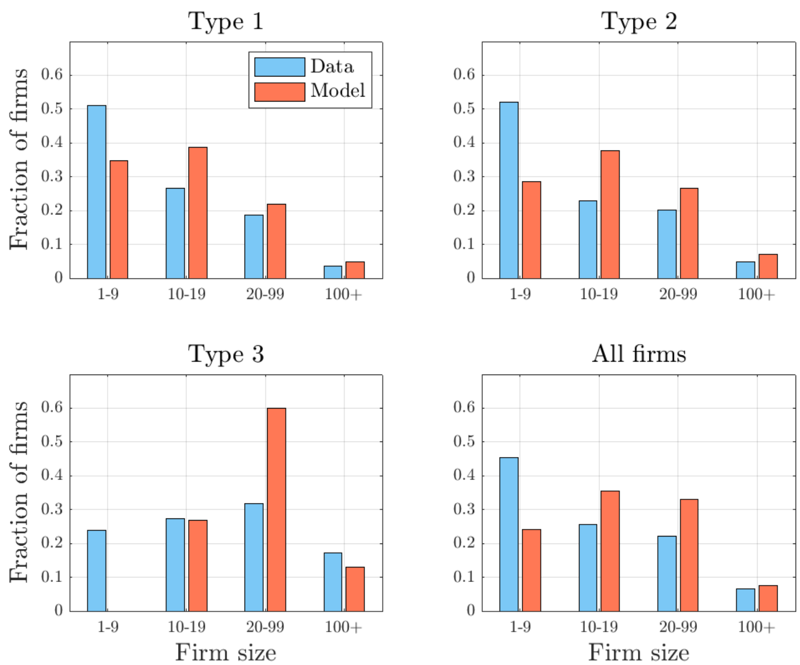

Figure 3.5: Untargeted moments: Distribution of firms by firm type

Overall, the model captures salient features of Sub-Saharan African economies. This implies that the quantitative model is a useful framework to study the consequences of a reduction in border delays for macroeconomic aggregates, to which we turn to next.

4 .3 The effects of border delays

We now simulate a counterfactual economy in which border delays are eliminated, implying $\psi = 1$. A key finding is that reducing border delays from their current levels down to zero results in an increase of aggregate output of 14.0%.

The full results are presented in Table 3.4. The column 'Benchmark' shows results from the calibrated economy described above. To compute the moments from the economy without delays, shown in the second column, we set the probability that an order of foreign capital is delivered to $\psi = 1$.

In the economy without delays, firms no longer face any delivery risk. This increases the expected return to foreign capital investments and encourages capital accumulation. Consequently,

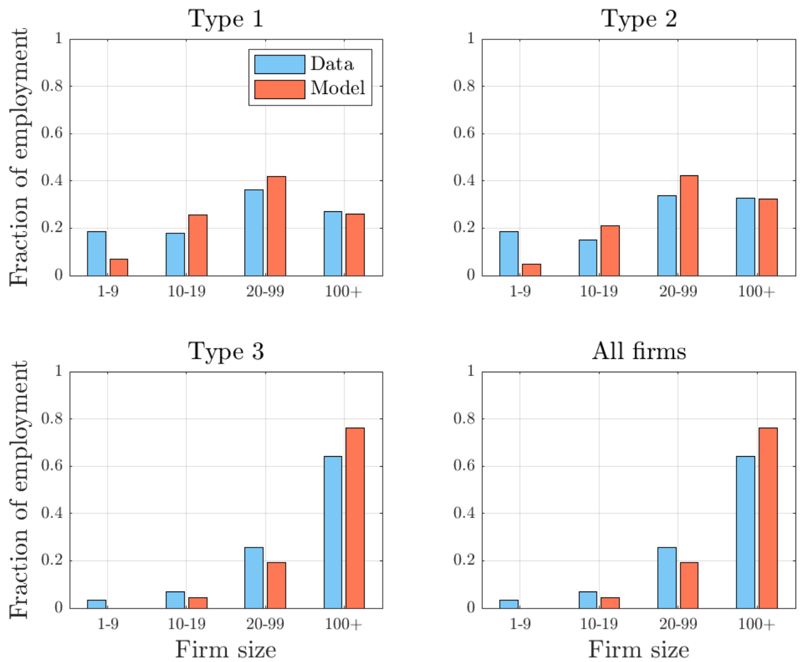

Figure 3.6: Untargeted moments: Distribution of employment by firm type

aggregate foreign capital increases, while undelivered orders fall to zero. Because foreign and local capital are complements in production, the removal of border delays also increases aggregate local capital.

The bottom half of Table 3.4 shows the effects on the distribution of firms. A key result is that the fraction of type 3 firms increases. This happens because the removal of border delays directly benefits type 3 firms, whose value consequently goes up. This in turn increases the threshold value $\bar{\xi}_2$, which pins down the maximum fixed cost that type 2 firms are willing to incur to upgrade. This then increases the value of type 2 firms and leads to more type 1 firms upgrading as well. In this way, the removal of border delays creates an extensive-margin effect that leads to an increase in the fraction of type 3 firms by almost 15 percentage points. In terms of employment in type 3 firms, the effects are even stronger. Because type 3 firms now accumulate more capital than in the economy with border delays, they have a higher demand for labor. The employment share of type 3 firms increases from 50% to 83%.

This reallocation of labor across firm types is reinforced in general equilibrium. The increase in firm value leads to a higher real wage through the free-entry condition (3.13). Type 1 firms use labor as the sole factor of production. A given increase in the wage rate leads to a stronger reduction in labor demand for those firms than for firms that also use local and foreign capital. This channel further lowers the employment share of type 1 firms.

Finally, the higher real wage creates an income effect for the representative household, leading to a reduction of overall labor supply.

	Benchmark	No delays
Average border delays (in days)	13.8	0
Aggregate output	1.00	1.14
Local capital	1.00	1.17
Foreign capital	1.00	2.07
Outstanding orders	1.00	0
Labor supply	1.00	0.92
Wage rate	1.00	1.14
Mass of firms	1.00	0.95
Fraction of type 1 firms	0.48	0.35
Fraction of type 2 firms	0.27	0.24
Fraction of type 3 firms	0.26	0.41
Employment share type 1 firms	0.31	0.09
Employment share type 2 firms	0.19	0.09
Employment share type 3 firms	0.50	0.83

Table 3.4: Consequences of elimination of border delays

Note.– The column 'no delays' shows results for the stationary equilibrium of the economy with the same parameters as the benchmark model, except that $\psi = 1$.

Decomposition. Aggregate output increases by 14.0% when border delays are eliminated. We show a decomposition of these gains in Figure 3.7. The increase in output is due to four distinct channels: a selection margin, a reallocation margin, a change in the mass of firms, and a general equilibrium effect. Figure 3.7 is organized as follows. On the left side, we normalize the size of the four areas, they correspond to the different channels. The overall size of the left bar is normalized to one, representing output in the baseline economy with input delays. The right bar corresponds to the economy without frictions. The size of the bar represents the overall gain in output compared to the baseline economy, +14%. The size of each area indicates the output gain from the associated channel. A change in the size of an area represents a proportional change in output from a specific channel.

To study the selection margin, we recompute total output using the distribution of firm types from the frictionless economy, holding all else constant at its baseline level, i.e., firms' policy functions and total mass of firms. The selection margin increases total output because more firms choose to pay the fixed upgrading costs to eventually become type 3 firms. Type 3 firms are larger and more productive on average, which implies that the higher fraction of type 3 firms increases output. This is represented by the light blue area labeled "Selection" in Figure 3.7. The selection margin is an important reason for the increase in aggregate output.

The second channel, shown in red in Figure 3.7, is the total mass of firms in the economy. To compute this channel we hold all policies fixed from the baseline economy and compute aggregate output using the mass of firms from the economy without delays. When the border delays are removed, firms increase their labor demand, implying that the total mass of firms must fall in order

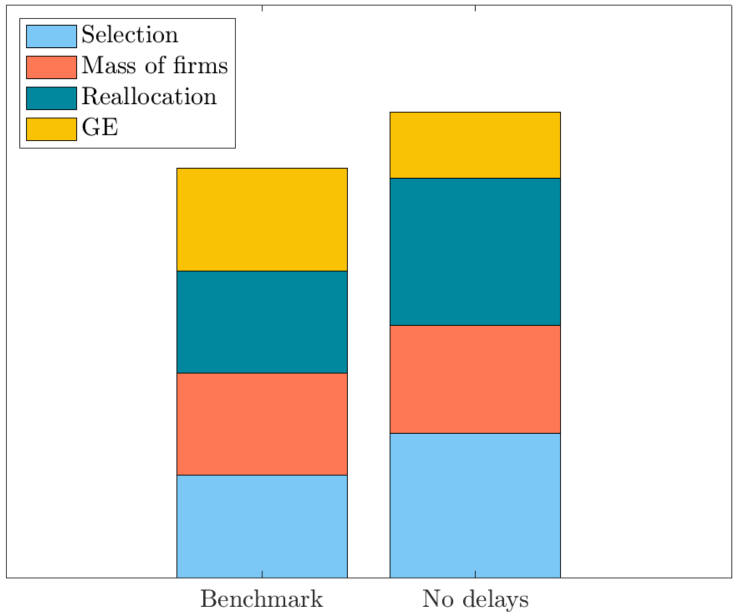

Figure 3.7: Decomposition

Notes.– The left bar is normalized to size one. All four areas are normalized to 1/4. The right bar represents total output in the economy without delays. The size of the areas compared to the left bar represents the gain in aggregate output from the respective channel, holding everything else constant.

to clear the labor market. This channel has a small negative effect on total output.

Similarly to the selection margin, the reallocation channel has a large positive effect on output. It is represented by the teal area in Figure 3.7. We compute its contribution by holding the fraction of each firm type constant from the baseline economy. Total output is then calculated using each firm type's average output from the economy without delays. The output gains are due to an improved allocation of factors of production within firm types. While the reallocation gains for type 1 and type 2 firms are negligible, output in type 3 firms grows significantly. This occurs primarily because in the economy without delays there are no firms with outstanding orders, i.e., firms that have received less than their chosen amount of foreign capital. The heterogeneity in the delivery status of previously ordered foreign capital disappears and average output for type 3 firms increases. Capital, labor, and output is reallocated from type 3 firms with delays to those without delays.

Finally, we quantify the general equilibrium effect of the removal of border delays. To do so, we recompute the baseline economy at the equilibrium wage rate that results from the removal of all delays. Compared to the baseline economy, the wage rate increases. This lowers labor demand and total output, especially for labor-intensive type 1 firms. The effects are represented by the yellow areas in Figure 3.7.

Delays as correlated distortions. Border delays lead to a misallocation of factors, More specifically, they create a distortion which is positively correlated with productivity. The literature on factor misallocation has identified such "correlated distortions" as being able to generate real effects of considerable magnitude (*cf.* Restuccia and Rogerson, 2008). In the context of our model, there are two reasons for a positive correlation of the distortion with firm-level productivity. First, only firms that import foreign inputs (type 3 firms) are directly affected by the friction. In addition, the fixed cost of upgrading is more likely to be paid by firms with higher idiosyncratic productivity. This implies that in equilibrium, type 3 firms are on average more productive. The import delay friction is therefore strongest for firms with higher average productivity. Figure 3.8 shows the distribution of output among type 3 firms in the economies with and without delays. In the baseline economy with border delays (blue bars), almost three quarters of output is produced by firms with very high productivity. Once the friction is removed, more firms upgrade to type 3 firms. The red bars in Figure 3.8 show the reallocation of production caused by this change. Because the critical productivity thresholds for upgrading fall when delays go down, more firms with relatively lower productivity levels now become type 3 firms.

The distortion also interacts with *changes* in firm-level productivity. Type 3 firms which receive a negative productivity shock and wish to shrink, can sell their installed capital with certainty. On the other hand, firms with positive productivity shocks that want to accumulate foreign capital will be subject to the delay friction. The impact of the friction is therefore higher when the gap between current and target capital is larger.

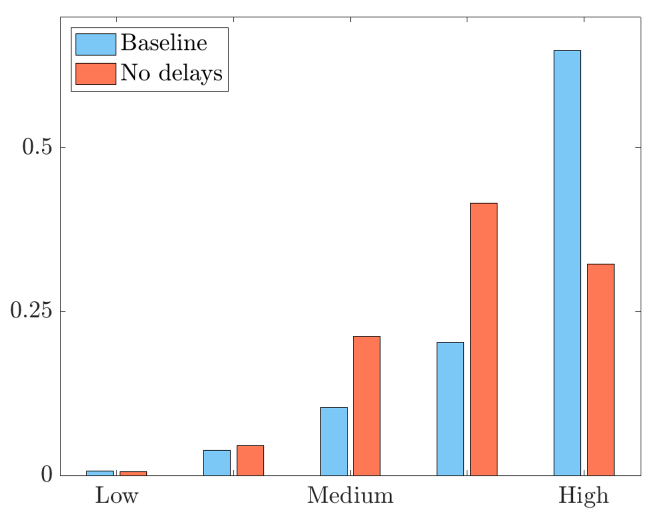

Figure 3.8: Distribution of output over productivity for type 3 firms

Notes.– The blue and the red bars each sum up to one. We group idiosyncratic productivity into five bins. The bars show the fraction of total output produced by type 3 firms in a given productivity bin. For each productivity level, the blue bars on the left show the baseline economy with delays, the red bars on the right show the economy without delays.

Border delays as a tax. The misallocation literature often represents distortions in the form of wedges, or 'taxes' on factor demand (*cf.* Restuccia and Rogerson (2008), Hsieh and Klenow (2009)). In the model described above, we explicitly modeled a concrete distortion and found it to be quantitatively important. An alternative approach would be to completely abstract from the exact type of friction and simply model border delays as a 'tax'. In our model, border delays increase the cost of foreign capital investments by creating uncertainty about the time of their delivery. We therefore ask: What would be the tax on foreign capital investments that generates the same aggregate output as the benchmark model with delays?

To answer this question, we start from our baseline model but eliminate all border delays (i.e. $\psi = 1$). We then introduce a tax τ on positive foreign capital investment and find the level of the tax which generates the same level of aggregate output we obtained in the baseline economy with border delays. The results show that the 13.8 days of average border delays we observe in the Sub-Saharan African data are equivalent to a 36.9% tax on foreign capital investment.

5 Conclusion

Using the WBES data, we documented that not only are border delays of inputs pervasive across Sub-Saharan Africa, they are also several orders of magnitudes larger than in richer countries. To assess their effects on firms and on the macroeconomy, we developed a dynamic general equilibrium model of heterogeneous firms. In the model, firms differ in productivity, their technology choice, and their levels of local and foreign capital. Importantly, not all firms are subject to delays because smaller, less productive firms opt for a production technology that only uses labor and local capital. Firms that choose to import foreign capital face a probability that those imports are delayed, leading to a suboptimal allocation of factors.

We find that when border delays are eliminated, aggregate output increases by 14%. These effects are mainly explained through selection and reallocation. The delays represent a distortion that is positively correlated with firms' productivity, affecting mainly the largest, most productive firms in the economy. Once the delays are removed, more firms choose to import foreign inputs and operate a more advanced technology. In this way, factors are reallocated towards more productive firms.

In terms of their effect on aggregate output, border delays are significant: we estimate that the observed average border delay is equivalent to a 36.9% tax on foreign capital investments. Our analysis suggests that simplifying and streamlining the border procedures for imported inputs in Sub-Saharan Africa should be a high-priority item on the region's agenda.

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A. Appendix to Article 1

1 Data: complement

Table A.1: Transition from informality to the formal economy in SSA

Country	Obs	Prop. NR	Age at reg.	Size at start		Size		Avg. annual growth		Fin. const.	Taxes (med. 1960-2021)	
				R	NR	R	NR	R	NR		Profit	Payroll
Angola	360	35.30	3.29	10	10	19	14	8.06	2.92	39.37	9.00	25.20
Gabon	179	35.02	2.35	8	6	12	8	3.90	1.18	30.69	24.90	19.10
Nigeria	2676	30.73	7.49	8	6	10	8	1.58	2.19	33.03	13.50	21.00
Uganda	762	29.62	3.56	5	3	8	7	5.57	6.25	20.63	11.30	22.10
Chad	153	28.16	5.68	6	6	6	6	0.00	0.00	40.86	28.40	31.30
Somalia	250	24.99	1.64	10	8	10	11	0.00	5.15	5.80	0.00	0.00
Liberia	151	23.33	4.24	7	6	13	14	3.44	4.50	38.84	5.40	17.30
Gambia	151	22.30	5.96	5	3	9	6	4.14	7.25	63.37	12.70	6.10
Burkina Faso	394	22.14	4.67	5	3	10	7	5.28	7.18	74.82	21.40	16.20
Ghana	720	20.70	5.88	6	4	10	7	5.57	4.77	62.37	14.70	18.00
South Sudan	738	19.38	3.13	6	5	8	8	6.05	8.84	49.95	19.20	8.10
Togo	150	18.48	5.30	6	5	15	5	5.51	6.14	51.17	26.50	10.70
Cabo Verde	156	18.08	11.68	6	3	8	6	1.66	3.36	36.60	18.50	18.60
Tanzania	813	17.96	4.79	7	4	10	6	2.07	3.46	45.29	18.00	20.40
Cameroon	361	15.86	3.32	6	5	7	6	1.52	2.31	40.32	18.30	30.00
Mauritius	398	15.66	9.94	4	3	10	5	4.86	0.00	46.42	7.80	10.40
Zambia	720	14.45	4.55	6	4	11	9	4.66	7.87	27.43	10.40	2.00
Lesotho	151	13.48	4.51	5	2	10	6	3.66	8.12	29.51	0.00	10.80
Mali	185	13.43	9.07	9	6	15	14	1.91	4.50	61.01	34.30	11.20

Continues on next page ...

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Table A.1 – continued from previous page

Country	Obs	Prop. NR	Age at reg.	Size at start		Size		Avg. annual growth		Fin. const.	Taxes (med. 1960-2021)	
				R	NR	R	NR	R	NR		Profit	Payroll
Mauritania	150	12.84	8.76	7	5	16	8	5.02	4.01	52.43	8.70	0.00
Niger	151	12.15	12.78	7	4	14	9	3.32	5.58	27.53	20.20	20.30
Burundi	157	12.01	6.48	7	6	15	16	7.28	2.09	36.67	10.20	28.50
Côte d'ivoire	361	11.84	5.73	5	4	9	6	4.01	4.01	69.14	20.10	8.80
Namibia	580	11.75	5.98	5	5	8	8	7.72	4.56	37.78	1.00	17.70
Senegal	601	11.70	5.54	8	6	10	10	3.72	2.26	50.86	24.00	16.20
Madagascar	532	10.83	5.15	8	3	10	11	2.01	4.75	12.29	20.30	18.00
Rwanda	241	10.20	4.81	5	6	11	8	9.60	2.60	35.13	5.70	25.70
Kenya	1001	9.45	5.99	5	4	9	9	5.60	7.25	29.26	6.80	30.10
Benin	150	9.38	4.55	5	5	20	12	9.93	2.65	43.32	26.40	15.20
Malawi	523	8.85	9.47	8	5	14	10	2.83	3.46	35.16	6.10	21.70
Central. Afr. Rep.	150	7.87	2.63	10	6	13	8	2.66	1.31	46.00	19.80	0.00
Sierra Leone	152	7.70	2.71	6	3	8	15	2.20	10.58	64.10	11.30	18.20
Eswatini	150	5.85	1.93	8	5	15	12	3.34	8.78	10.05	4.50	28.10
Mozambique	601	4.66	7.40	8	5	12	6	1.38	0.73	17.35	4.50	30.40
Botswana	268	4.52	4.25	6	6	15	8	6.42	3.04	25.82	0.00	21.50
South Africa	1097	4.37	22.82	8	5	14	11	2.26	1.78	8.67	4.00	23.70
Ethiopia	848	4.25	2.69	5	3	10	7	9.60	6.73	20.27	3.90	26.40
Guinea	150	3.08	2.35	5	3	9	6	6.99	10.50	30.41	28.60	0.00
Zimbabwe	600	2.63	4.16	9	10	10	13	0.00	-1.42	55.88	5.10	17.60
Sudan	662	2.34	14.57	12	10	15	12	0.59	1.08	15.54	19.20	13.80
Djibouti	266	1.51	3.38	7	6	12	16	4.26	6.32	11.92	17.70	17.70

Notes. Table shows data summaries by country. Columns Obs through Financial const are computed based on the WBES data, while Taxes are from the Doing Business data. Obs stands for number of observations, Prop. NR for proportion of firms not registered at start among formal firms, Age at reg. for age at registration for firms that did not register at start, NR for not registered at start and R for registered at start, Financial const. for financial constraint measured by the proportion of firms for whom the financial constraints are major or very severe obstacle. Growth is computed with respect to full time employment.

2 Proof

Cutoff fixed cost of formalization

Recall the problem of informal and new entrepreneurs:

$$V_i(\varepsilon_t, a_t) = \max_{\xi^*} \int_0^{\xi^*} \widetilde{V}_f(\varepsilon_t, a_t, \xi) d\mathcal{U}(\xi) + \int_{\xi^*}^{\Xi} \widetilde{V}_i(\varepsilon_t, a_t) d\mathcal{U}(\xi)$$

$$V_i(\varepsilon_t, a_t) = \max_{\xi^*} \int_0^{\xi^*} \widetilde{V}_f(\varepsilon_t, a_t, \xi) d\mathcal{U}(\xi) + [1 - F_\xi(\xi^*)] \widetilde{V}_i(\varepsilon_t, a_t)$$

First order condition (FOC), assuming interior solution:

$$V_i(\varepsilon_t, a_t) = \frac{\partial}{\partial \xi^*} \left[\int_0^{\xi^*} \widetilde{V}_f(\varepsilon_t, a_t, \xi) d\mathcal{U}(\xi) \right] - f_\xi(\xi^*) \widetilde{V}_i(\varepsilon_t, a_t) = 0$$

$f_\xi(\xi^*) = 1$, and $\frac{\partial}{\partial \xi^*} \left[\int_0^{\xi^*} \widetilde{V}_f(\varepsilon_t, a_t, \xi) d\mathcal{U}(\xi) \right] = \widetilde{V}_f(\varepsilon_t, a_t, \xi^*)$ using the Leibniz formula for the derivative of an integral with functional bounds.[1] Therefore, the FOC implies:

$$\widetilde{V}_f(\varepsilon_t, a_t, \xi^*) = \widetilde{V}_i(\varepsilon_t, a_t), \qquad QED.$$

[1] $\frac{\partial}{\partial \alpha} \int_{a(\alpha)}^{b(\alpha)} h(y, \alpha) dy = h(b(\alpha), \alpha) \cdot \frac{\partial b(\alpha)}{\partial \alpha} - h(a(\alpha), \alpha) \cdot \frac{\partial a(\alpha)}{\partial \alpha} + \int_{a(\alpha)}^{b(\alpha)} \frac{\partial h(y, \alpha)}{\partial \alpha} dy.$

B. Appendix to Article 2

1 Proofs

1 .1 Proposition 1

Case 1: No delay on investment delivery

$$\begin{aligned}
NPV_0(i_{f,t}) &= -i_{f,t} + \beta i_{f,t}^{\alpha} + \beta^2 \left[(1-\delta_f) i_{f,t}\right]^{\alpha} + \beta^3 \left[(1-\delta_f)^2 i_{f,t}\right]^{\alpha} + \cdots + \beta^j \left[(1-\delta_f)^{j-1} i_{f,t}\right]^{\alpha} + \ldots \\
&= -i_{f,t} + \sum_{j=1}^{\infty} \beta^j \left[(1-\delta_f)^{j-1} i_{f,t}\right]^{\alpha} \\
&= -i_{f,t} + \beta i_{f,t}^{\alpha} \sum_{j=1}^{\infty} \beta^{j-1} (1-\delta_f)^{\alpha(j-1)} \\
&= -i_{f,t} + \beta i_{f,t}^{\alpha} \sum_{j=0}^{\infty} \left[\beta (1-\delta_f)^{\alpha}\right]^{(j)} \\
NPV_0(i_{f,t}) &= -i_{f,t} + \frac{\beta}{1-\beta(1-\delta_f)^{\alpha}} i_{f,t}^{\alpha}
\end{aligned}$$

Case 2: investment is subject to delivery delay

Pose: $V^{(j)}(i_{f,t}) = \beta^j i_{f,t}^{\alpha} + \beta^{j+1} \left[(1-\delta_f) i_{f,t}\right]^{\alpha} + \beta^{j+2} \left[(1-\delta_f)^2 i_{f,t}\right]^{\alpha} + \cdots + \beta^{j+k} \left[(1-\delta_f)^k i_{f,t}\right]^{\alpha} + \ldots$ the discounted value of future revenues from $i_{f,t}$, if $i_{f,t}$ is delivered at time $t+j$; and $m_j = (0,0,...,1,0,0,...)$ the discrete probability distribution that places weight 1 in the j^{th} period. m_j corresponds to a delay of j periods with certainty. This is the case of the most common *time to build* (Kydland and Prescott, 1982; Altug, 1989; Rouwenhorst, 1991; Chang, 1995; Christiano and Todd, 1996; Casares, 2006). Moreover, any delay system characterized by a discrete probability distribution $m = (p_1, p_2, ..., p_k, ...)$ is a convex combination of the elements of the canonical base $\{m_j\}_{j=1}^{\infty}$. Thus:

$$NPV_0(i_{f,t}) = -i_{f,t} + V^{(1)}(i_{f,t}) = NPV_{m_1}(i_{f,t}), \quad \textit{and}$$

$$NPV_m(i_{f,t}) = -i_{f,t} + \sum_{k=1}^{\infty} p_k V^{(k)}(i_{f,t})$$

Finally, notice that by construction $V^{(j+k)}(i_{f,t}) = \beta^k V^{(j)}(i_{f,t}) \leq V^{(j)}(i_{f,t})$, $\forall k \geq 0$. Therefore $V^{(1)}(i_{f,t}) = \max_{j \geq 1} V^{(j)}(i_{f,t})$, and $NPV_0(i_{f,t}) = NPV_{m_1}(i_{f,t}) = \max_{m} NPV_m(i_{f,t})$. *QED.*

1 .2 Proposition 2

From proof 1 .1 it is straightforward that $NPV_m(i_{f,t})$ is invariant with respect to m if $\beta = 1$, because then $V^{(j+k)}(i_{f,t}) = \beta^k V^{(j)}(i_{f,t}) = V^{(j)}(i_{f,t})$, $\forall k \geq 0$. That is delivery delay doesn't matter if the future is not discounted. This result is intuitive however.

2 Frictionless economy steady state derivation

In the frictionless economy, we have $z = 1$, $o_f = 0$, $k'_f = (1-\delta_f)(k_f + i_f)$, $\forall$ t. So, $i_f = \Delta k'_f - k_f$ and $k_f + i_f = \Delta k_f$, where $\Delta = \dfrac{1}{1-\delta_f}$. Then the problem of the firm is:

$$V(k_f) = \underset{k_l, k'_f}{max} \ \left\{ \left[-1 + \beta(1-\delta_l)\right] k_l - (\Delta k'_f - k_f) + \beta \left[\pi(k_l, \Delta k'_f) + V(k'_f)\right] \right\} \tag{B.1}$$

We pose $f(k_l, k_f) = \left[\psi k_l^\rho + (1-\psi) k_f^\rho\right]^{\frac{1}{\rho}}$, derive the first order conditions of (B.1) and apply the envelop condition to get:

$$\begin{cases} \beta \tilde{\Gamma} k_l^{\rho-1} \left[f(k_l, \Delta k'_f)\right]^{\tilde{\alpha}-\rho} = 1 - \beta(1-\delta_l) \\ \beta \hat{\Gamma} (\Delta k'_f)^{\rho-1} \left[f(k_l, \Delta k'_f)\right]^{\tilde{\alpha}-\rho} = \Delta - \beta \end{cases}$$

where $\tilde{\Gamma} = \tilde{\alpha}\Gamma\psi$, $\hat{\Gamma} = \tilde{\alpha}\Gamma(1-\psi)$. Finally, solving this system yields $k'_f = \left(\dfrac{\Delta - \beta}{\hat{\hat{\Gamma}}}\right)^{\frac{1}{\tilde{\alpha}-1}}$, $k_l = \tilde{\tilde{\Gamma}} \Delta k'_f$, and $i_f = (\Delta - 1) k'_f$, with $\tilde{\tilde{\Gamma}} = \left[\dfrac{(1 - \beta(1-\delta_l))\,\Delta \hat{\Gamma}}{(\Delta - \beta)\tilde{\Gamma}}\right]^{\frac{1}{\rho-1}}$ and $\hat{\hat{\Gamma}} = \beta \hat{\Gamma} \left[f(\tilde{\tilde{\Gamma}}, 1)\right]^{\tilde{\alpha}-1} \Delta^{\tilde{\alpha}}$.

3 Robustness experimentations

3 .1 Elasticity of substitution between inputs

The elasticity of substitution σ between local and foreign inputs is a potentially sensitive parameter for the quantitative analyses as shown in propositions **??** and 4 .2. But we barely have estimate for the substitutability of inputs along this particular taxonomy in the literature, let alone for the specific countries this paper is interested in. Because of data constraints, I cannot either estimate the elasticity of substitution in this paper. However, there are estimates of the substitutability between various taxonomies of inputs in the literature that converge to show that inputs are mostly complement than substitute in general. Considering the information in Table B.1 , the value of 0.8 I pick for the analyses is in middle withing the range of the estimates made in the literature. In addition, I complement the analysis with robustness checks with different values of the elasticity of substitution σ. The results are reported in Table B.2 . The estimates with $\sigma = 0.8$ are fair. Note that in the experiments shown in the table the relative shares of local and foreign inputs are not held constant, because I recalibrate them each time to match the shares in the data. Even so, the effects of the border delays are much less strong with $\sigma = 2$.

Table B.1: Estimates of the elasticity of substitution between inputs in the literature

Inputs	Elasticity of substitution	Paper
Japan-originated and non-Japan-originated inputs	0.2	Boehm et al. (2019)
Material inputs	0.3, 0.5 or 1.5	Barrot and Sauvagnat (2016)
Capital equipment and unskilled labor	1.67	Krussel et al. (2000)
Capital equipment and skilled labor	0.67	
Capital equipment and capital structure	1.1	Chang (1995)
Water and other factors (capital, production workers and non-production workers)	Complements or very low substitutes	Babin, Willis and Allen (1982)
Seed and fertilizer	0.28	Miller, Bergtold, and Featherstone (2019)
Energy and non-energy inputs	≤ 0.54	Dissou and Ghazal (2010)
Labor and materials	1.5 to 4	Chan (2017)
Labor and energy	Perfect	Recka (2013)
The composit of labor and energy, and capital	0.13	

Table B.2: Robustness checks with respect to σ (Cameroon)

σ	Foreign inputs	Local inputs	Labor	Wage	Production	Consumption
0.5	17.93	5.83	1.09	3.75	4.09	1.74
0.8	18.46	2.67	3.24	1.87	4.94	3.55
1.5	22.91	2.87	3.79	1.25	6.19	4.53
2	15.77	-3.60	-1.49	1.22	1.25	0.38

Notes: The table shows for the different values of σ the percentage change of the aggregates in columns in the frictionless counterfactual compared to the baseline.

3 .2 Imported inputs structure

Whether imported inputs are materials or capital goods potentially matters for the effects of the delays. In the main experimentations of the paper I consider a mixture of both determined by the relative shares in the data. In this annex I perform a robustness and compute what the effects would be if imported inputs were only materials or only capital. The results are in Table B.3. As expected, the effect of the delays on foreign inputs is most important if imported inputs are only materials. On the other hand, the effects are the least when we consider only capital goods imported.

Table B.3: Robustness checks with respect foreign inputs structure (Cameroon)

Foreign inputs	Foreign inputs	Local inputs	Labor	Wage	Production	Consumption
Baseline model	18.46	2.67	3.24	1.87	4.94	3.55
Only materials	22.94	7.12	3.02	5.00	5.54	2.42
Only capital	6.32	0.57	1.40	1.25	0.03	-0.43

Notes: The table shows the percentage change of the aggregates in columns in the frictionless counterfactual compared to the baseline when foreign inputs are considered as only materials or only capital goods.

C. Appendix to Article 3

1 Data

This appendix includes descriptive statistics and explains key variables in more detail.

WBES questions used. To measure the use of foreign inputs by firms, to classify firms into types, and to measure border delays and firm employment, we rely on the following questions from the World Bank Enterprise Surveys.

D.12: "*In the last fiscal year, what percentage of this establishment's purchases of material inputs or supplies were: D12.a.) of domestic origin? D12.b.) of foreign origin?*"

D.13: "*Were any of the material inputs or supplies purchased in fiscal year imported directly?*"

D.14: "*In the last complete fiscal year, when this establishment imported material inputs or supplies, how many days did it take on average from the time these goods arrived to their point of entry (e.g. port, airport) until the time these goods could be claimed from customs?*"

L.1 "*At the end of the last fiscal year, how many permanent, full-time individuals worked in this establishment?*"

We use the answer to question D.13 to identify type 3 firms, i.e., those firms that import foreign inputs directly. From the answers to D.12 we are able to infer the foreign input share. The answers to question D.14 constitute our measure of border delays. Firm-level employment is taken from question L.1.

Descriptive statistics. In Tables C.1 and C.2 we report summary statistics of our main variables. For each country in our sample, the tables include the fraction of firms that uses foreign inputs, the share of foreign inputs (in %), the average border delays, the number of employees, and the country's 2010-level of real GDP in logs.

Country	Uses foreign inputs			Share of foreign inputs			Border delay			Full time employees			Log real GDP
	mean	sd	N	mean	sd	N	mean	sd	N	mean	sd	N	(2010)
Angola	0.63	0.48	139	43.40	25.93	88	11.43	10.66	42	34.27	49.17	349	25.26
Benin	0.69	0.47	148	76.78	30.37	106	14.06	15.08	77	45.44	107.51	150	22.93
Botswana	0.87	0.34	87	71.08	30.90	77	4.76	6.23	61	66.78	231.55	267	23.16
Burkina Faso	0.76	0.43	92	68.05	29.52	70	16.38	26.68	29	28.69	121.11	391	22.93
Burundi	0.79	0.41	60	63.11	33.04	45	32.39	30.51	29	38.47	78.67	157	21.72
Cameroon	0.63	0.48	350	52.03	33.45	209	23.39	25.77	70	23.17	58.87	360	23.91
Cabo Verde	0.58	0.50	74	81.37	28.25	48	20.51	15.35	30	20.37	46.72	152	21.12
Central Afr. Rep.	0.72	0.46	29	74.53	26.20	21	11.86	11.88	9	27.13	47.88	149	21.57
Chad	0.58	0.50	145	71.46	31.38	89	30.76	31.76	50	13.51	27.89	153	22.88
Côte d'ivoire	0.53	0.50	341	64.40	34.66	170	27.06	21.77	83	32.60	91.62	349	24.24
Djibouti	0.69	0.47	52	89.90	20.16	36	5.09	2.66	26	36.25	86.66	261	21.47
Eritrea	0.43	0.50	90	53.44	34.82	38	20.12	22.42	11	17.49	20.17	177	21.45
Ethiopia	0.38	0.49	363	46.68	30.69	166	19.49	16.09	126	37.88	132.80	832	24.41
Gabon	0.85	0.36	168	74.23	29.59	145	12.59	23.38	52	43.29	135.84	170	23.13
Gambia	0.63	0.48	150	75.21	30.22	87	21.39	21.55	45	17.29	34.51	151	21.02
Ghana	0.69	0.46	372	69.65	31.95	251	14.79	13.04	103	34.71	78.94	718	24.24
Guinea	0.74	0.44	137	84.35	23.66	105	18.09	17.20	92	20.39	51.29	149	22.67
Kenya	0.48	0.50	989	58.28	30.99	451	22.52	20.59	250	33.53	154.86	1000	24.61
Lesotho	0.60	0.49	125	69.71	33.74	82	4.42	6.87	72	60.15	1437.07	147	21.41
Liberia	0.46	0.50	150	75.34	28.60	73	8.08	6.07	31	27.05	41.76	151	21.63
Madagascar	0.32	0.47	394	68.29	37.41	139	15.50	19.25	79	67.70	192.70	515	23.02
Malawi	0.81	0.39	149	60.71	30.83	119	20.01	22.83	67	68.97	260.31	498	22.38
Mali	0.76	0.43	185	62.42	32.90	143	31.52	44.85	58	46.42	134.75	183	23.12
Mauritania	0.73	0.45	47	66.81	33.61	35	26.72	19.06	27	40.60	64.64	146	22.32
Mauritius	0.57	0.50	142	76.95	29.99	90	11.70	14.72	62	42.96	152.06	398	23.00
Mozambique	0.46	0.50	597	61.14	34.31	259	21.58	25.85	177	40.45	98.61	601	23.15

Table C.1: Descriptive statistics 1/2

Notes.– See notes under Table C.2

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Country	Uses foreign inputs			Share of foreign inputs			Border delay			Full time employees			Log real GDP
	mean	sd	N	mean	sd	N	mean	sd	N	mean	sd	N	(2010)
Namibia	0.45	0.50	153	51.25	38.23	89	5.44	9.27	66	22.83	50.82	568	22.90
Niger	0.57	0.50	132	74.80	26.04	78	28.25	31.66	44	35.98	82.35	150	22.71
Nigeria	0.34	0.47	972	48.19	26.95	398	9.00	14.27	142	20.78	107.67	2564	26.67
Rwanda	0.62	0.49	74	58.39	36.88	52	14.27	25.69	38	36.20	100.09	238	22.52
Senegal	0.41	0.49	234	44.73	31.81	79	17.93	17.84	31	58.08	214.85	596	23.40
Sierra Leone	0.48	0.50	152	62.31	33.69	90	12.48	8.60	29	14.48	21.37	152	21.96
Somalia	0.86	0.34	247	58.62	31.51	197	6.85	12.05	74	20.08	32.84	250	22.06
South Africa	0.08	0.27	1071	44.66	21.56	114	10.67	13.36	44	51.50	277.71	1093	26.38
South Sudan	0.87	0.33	89	65.51	27.25	77	15.10	19.99	40	13.09	22.84	733	23.83
Sudan	0.66	0.48	101	53.77	26.95	67	6.40	2.80	28	26.68	39.01	660	24.71
Eswatini	0.46	0.50	102	64.79	30.76	53	4.04	4.55	66	35.72	85.45	149	21.98
Tanzania	0.63	0.48	355	52.11	30.33	244	29.13	18.70	71	24.23	104.76	718	24.27
Togo	0.60	0.49	149	71.92	31.46	91	30.56	34.59	75	48.83	104.43	150	21.86
Uganda	0.40	0.49	368	33.86	28.84	145	19.44	16.53	56	19.53	116.60	740	23.93
Zambia	0.49	0.50	354	54.10	27.29	157	14.47	12.79	106	24.95	54.50	714	23.53
Zimbabwe	0.66	0.47	592	58.14	32.93	374	8.99	11.05	247	31.88	434.95	600	23.37

Table C.2: Descriptive statistics 2/2

Notes.– The columns labeled "Uses foreign inputs" report answers to *D12.b*, assigning a value of 1 to responses larger than zero and 0 otherwise. The columns "Share of foreign inputs" report answers to *D12.b* for firms with $D12.b > 0$. The shares are expressed in %. The columns "Border delay" and "Full time employees" respectively report answers to *D.14* and *L.1*. Source: World Bank Enterprise Survey, World Bank World Development Indicators, and authors' calculations.

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Border delays in non-SSA countries. – In Figure C.1 we replicate Figure 3.2 for Russia, Thailand, Italy, Germany, Spain, Turkey and Sweden. The differences are stark. Although the maximum delay in Russia is comparable to that observed in some Sub-Saharan African countries, the overall distribution is more concentrated towards low delays in all these countries. For comparison, average delays are 2.6 days in Sweden and Turkey, under five days in Spain and Germany, and around 6 to 7 days in Thailand, Italy and Belgium. These are 4 to 15 times lower than the average delay in Burundi, Mali or Togo.

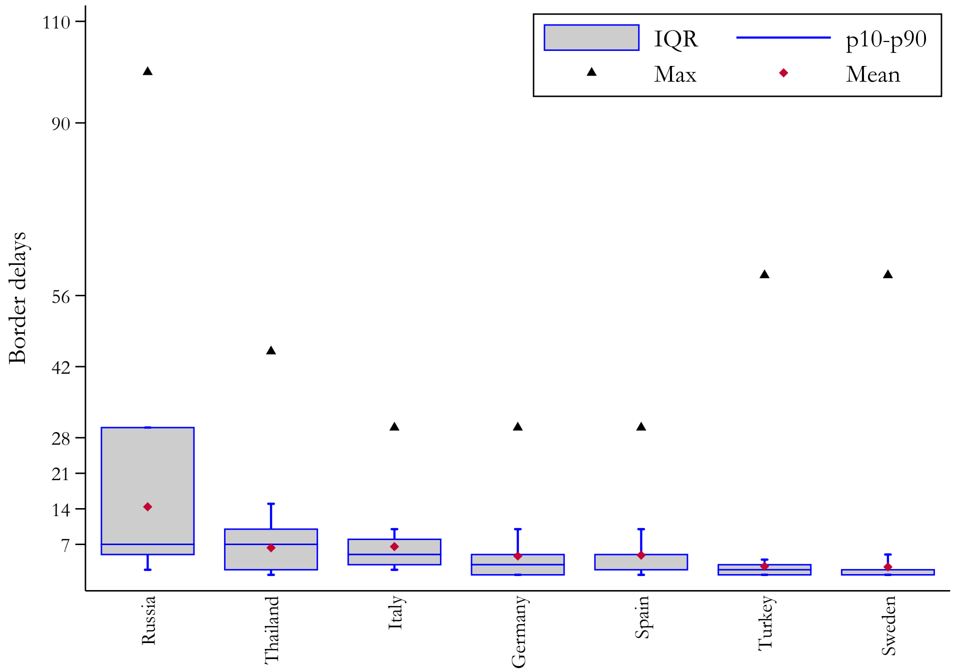

Figure C.1: Border delays in other countries

Notes.– The figure shows country-specific distributions of border delays in days. The box plots cover the 25th to 75th percentiles of delays. Medians are indicated by the horizontal bar. The lines extending from the boxes show the 10th and 90th percentiles. Averages are shown as red diamonds. The black triangles show the maximum delays. Minimum delays were zero in all cases. Source: World Bank Enterprise Survey and authors' calculations.

2 Model derivations

For the computational solution, we define a firm's value function *after* production and *after* the firm learns its future level of productivity, but *before* the fixed cost of upgrading is drawn. At this point the firm decides on a threshold fixed cost level $\bar{\xi}_j$. If the fixed cost draw is below the threshold, the firm decides to upgrade to the next level, otherwise it does not. We derive the following terms to simplify the firm problem.

Labor demand. Firms' optimal labor demand is static, given the state s. Taking the first-order conditions of (3.7), (3.10), and (3.12) with respect to n yields

$$n^1(\varepsilon) = \left(\frac{\mu_1 \zeta \varepsilon}{w}\right)^{\frac{1}{1-\zeta}}, \qquad n^2(\varepsilon, k_l) = \left(\frac{\mu_2 \beta \varepsilon \cdot k_l^{\alpha}}{w}\right)^{\frac{1}{1-\beta}}, \quad \text{and}$$
$$n^3(\varepsilon, k_l, k_f) = \left(\frac{\mu_3 \beta \varepsilon \cdot k(k_l, k_f)^{\alpha}}{w}\right)^{\frac{1}{1-\beta}}. \tag{B.1}$$

For a type 2 firm, labor demand depends positively on local capital in place. For a type 3 firm, labor demand also depends on the amount of foreign capital, but not on any outstanding order of foreign inputs. The term $k(\cdot)$ represents the CES aggregate of k_l and k_f as described by equation (3.3).

Capital demand. Revenue minus labor costs for a type 1 firm, evaluated at the optimal labor choice given in (B.1), can be written as

$$\Pi^1(\varepsilon) = \varepsilon^{\frac{1}{1-\beta}} \left(\frac{\beta}{w}\right)^{\frac{\beta}{1-\beta}} \cdot (1-\beta). \tag{B.2}$$

A type 2 firm's optimal labor choice implies that revenue minus labor costs becomes

$$\Pi^2(\varepsilon, k_l) = (\mu\varepsilon)^{\frac{1}{1-\beta}} \left(\frac{\beta}{w}\right)^{\frac{\beta}{1-\beta}} k_l^{\frac{\alpha}{1-\beta}} (1-\beta) \equiv A_2 k_l^{\hat{\alpha}}, \tag{B.3}$$

with $A_2 = (\mu\varepsilon)^{\frac{1}{1-\beta}} \left(\frac{\beta}{w}\right)^{\frac{\beta}{1-\beta}} (1-\beta)$ and $\hat{\alpha} = \frac{\alpha}{1-\beta}$. Because raising local capital is frictionless, k_l is not a state variable for a type 2 firm. This implies that the intertemporal investment problem of a future type 2 firm is independent of the continuation value.[1] Therefore, the investment problem net of the continuation value and any potential upgrading costs can be written as

$$\max_{k_l} -k_l + \rho \left[(1-x)\left(A_2 k_l^{\hat{\alpha}} + (1-\delta)k_l\right) + x\theta k_l\right], \tag{B.4}$$

with closed form solution $k_l^* = \left(\frac{A_2 \hat{\alpha}}{\tilde{r}}\right)^{\frac{1}{1-\hat{\alpha}}}$, where the effective user cost of local capital is $\tilde{r} = \frac{1}{\rho(1-x)} - 1 + \delta - \frac{x}{1-x}\theta$. Evaluating (B.4) at k_l^* yields

$$A_2^{\frac{1}{1-\hat{\alpha}}} \left(\frac{\hat{\alpha}}{\tilde{r}}\right)^{\frac{\hat{\alpha}}{1-\hat{\alpha}}} \rho(1-x)(1-\hat{\alpha}) \equiv \rho(1-x)\Pi_2(\varepsilon). \tag{B.5}$$

A type 3 firm's static profits net of wage costs from (3.12), evaluated at the optimal labor

[1] Implicitly, a firm liquidates all capital k_l after production and then raises the future desired capital stock k_l' as equity.

decision can be written as

$$\Pi^3(\varepsilon, k_l, k_f) = \varepsilon^{\frac{1}{1-\beta}} \left(\frac{\beta}{w}\right)^{\frac{\beta}{1-\beta}} \cdot k(k_l, k_f)^{\frac{\alpha}{1-\beta}} \cdot (1-\beta) \equiv A_3 k(k_l, k_f)^{\hat{\alpha}}, \tag{B.6}$$

with $A_3 = \varepsilon^{\frac{1}{1-\beta}} \left(\frac{\beta}{w}\right)^{\frac{\beta}{1-\beta}} (1-\beta)$. Because total effective capital is a CES of local and foreign capital, no analytical solution exists for the optimal choice k_l. The local capital investment problem net of the continuation value, the foreign capital choice, and any potential upgrading costs can be written as

$$\max_{k_l} -k_l + \rho \left[(1-x)\left(A_3 \mathbb{E}_\psi k(k_l, k_f)^{\hat{\alpha}} + (1-\delta)k_l\right) + x\theta k_l\right], \tag{B.7}$$

with an implicit optimal level given by $k_l^* = \phi \left(\frac{\hat{\alpha} A_3 \mathbb{E}_\psi k(k_l^*, k_f)^{\hat{\sigma}}}{r_l}\right)^{\sigma}$, where the effective user cost of local capital is $r_l = \frac{1-\rho\cdot(1-x(1-\theta))}{(1-x)\rho} + \delta$, and $\hat{\sigma} = \frac{1+\sigma(\hat{\alpha}-1)}{\sigma}$.[2] The value of effective capital k in (B.7) is not known at the time of the local capital investment decision because the future level of foreign capital depends on the outcome of the delivery process.

Value functions. We now define each firm type's value function *after* production and the realization of future productivity, but *before* the fixed cost of upgrading is drawn. The known level of future productivity is denoted ε. The value of a type 1 firm at this point is denoted as $W^1(\varepsilon)$.

$$\begin{aligned} W^1(\varepsilon) \quad &= \max_{\bar{\xi}_1} \int_{\bar{\xi}_1}^{\infty} \rho(1-x)\left[\Pi^1(\varepsilon) + \sum_{k=1}^{K} \pi_{ik} W^1(\varepsilon_k)\right] dG(\xi_1) + \\ &\int_0^{\bar{\xi}_1} \max_{k_l} -\xi_1 + \rho(1-x)\left(\Pi^2(\varepsilon) + \sum_{k=1}^{K} \pi_{ik} W^2(\varepsilon_k)\right) dG(\xi_1) \end{aligned} \tag{B.8}$$

From (B.8) the cutoff value $\bar{\xi}_1$ which makes firms indifferent between upgrading or not, has a closed form solution which does not depend on the particular assumption about the distribution of the fixed cost. The cutoff is given by the difference between the value of upgrading the firm or not:

$$\bar{\xi}_1(\varepsilon) = W_u^1(\varepsilon) - W_{nu}^1(\varepsilon), \tag{B.9}$$

[2] This derivative of (B.7) with respect to k_l is given by:

$$-1 + \rho(1-x)\left(A_3 \hat{\alpha} \mathbb{E}_\psi k(k_l, k_f)^{\hat{\alpha}-1} \cdot \phi^{\frac{1}{\sigma}} k_l^{-1/\sigma} \cdot \mathbb{E}_\psi k(k_l, k_f)^{1/\sigma} + 1 - \delta\right) + \rho x\theta$$

The exponents on $k(k_l, k_f)$ combine to $\hat{\sigma}$.

where

$$\begin{aligned} W^1_{nu}(\varepsilon) &= \rho(1-x)\left[\Pi^1(\varepsilon) + \sum_{k=1}^{K} \pi_{ik} W^1(\varepsilon_k)\right] \\ W^1_{u}(\varepsilon) &= \rho(1-x)\left(\Pi^2(\varepsilon) + \sum_{k=1}^{K} W^2(\varepsilon_k)\right) \end{aligned}$$

This follows from taking the first order condition of B.8 with respect to $\bar{\xi}_1$, and applying the Leibniz formula for the derivative of an integral with functional bounds,

$$\frac{\partial}{\partial \alpha}\int_{a(\alpha)}^{b(\alpha)} h(y,\alpha)dy = h\left(b(\alpha),\alpha\right)\cdot\frac{\partial b(\alpha)}{\partial \alpha} - h\left(a(\alpha),\alpha\right)\cdot\frac{\partial a(\alpha)}{\partial \alpha} + \int_{a(\alpha)}^{b(\alpha)} \frac{\partial h(y,\alpha)}{\partial \alpha}dy.$$

Using our functional form assumption for $G(\xi_1)$ the expected fixed cost paid becomes $\int_0^{\bar{\xi}_1} \xi_1 dG(\xi_1) = \frac{\bar{\xi}_1^2}{2}\cdot\frac{1}{\Xi_1}$.

The value of a type 2 firm is denoted as $W^2(\varepsilon)$. If the firm is upgrading, it must choose an investment into future foreign capital. Because a type 2 firm's existing level and outstanding orders of foreign capital are zero, from (3.4) we have that the firm chooses $\tilde{o}_f$ directly. We denote as $\tilde{k}_f$ the amount of foreign capital in place for future production prior to depreciation.

$$\tilde{k}_f = \begin{cases} k_{f,-1} + \tilde{o}_f, & \text{with probability } \psi \\ k_{f,-1} & \text{with probability } 1-\psi \end{cases} \tag{B.10}$$

The amount $k_f = (1-\delta)\tilde{k}_f$ in (B.11) denotes the amount of foreign capital in place with which a firm makes next period's investment decision. Following the same steps as above, we can write a type 2 firm's problem as

$$\begin{aligned} W^2(\varepsilon) &= \max_{\bar{\xi}_2} \int_{\bar{\xi}_2}^{\infty} \rho(1-x)\left(\Pi^2(\varepsilon) + \sum_{k=1}^{K}\pi_{ik}W^2(\varepsilon_k)\right)dG(\xi_2) + \\ &\int_0^{\bar{\xi}_2}\left[\max_{k_l,\tilde{o}_f} -\xi_2 - k_l - \tilde{o}_f + \rho(1-x)\mathbb{E}_\psi\left(\Pi^3(\varepsilon,k_l,\tilde{k}_f) + (1-\delta)k_l + \right.\right. \\ &\left.\left.\sum_{k=1}^{K}\pi_{ik}W^3(\varepsilon_k,k_f,o_f)\right) + \rho x\theta\mathbb{E}_\psi(k_l+\tilde{k}_f)\right]dG(\xi_2), \end{aligned} \tag{B.11}$$

subject to the non-negativity constraint on foreign capital investment[3]. Optimality requires that k_f be chosen such that the expected marginal benefit of k_f equal the marginal cost of raising foreign capital. If the newly ordered foreign capital is delivered, the marginal benefit is an increase in future production and a higher continuation value. If the order is not delivered, the marginal benefit is an increase in o_f, which increases the continuation value of the firm.

Following the same steps as above, the cutoff value $\bar{\xi}_2$ determines the firm's upgrading rule. It

[3] For a type 2 firm, $k_{f,-1} = 0$

is given by

$$\bar{\xi_2}(\varepsilon) = W_u^2(\varepsilon) - W_{nu}^2(\varepsilon), \tag{B.12}$$

with

$$W_{nu}^2(\varepsilon) = \rho(1-x)\left(\Pi^2(\varepsilon) + \sum_{k=1}^{K} \pi_{ik} W^2(\varepsilon_k)\right),$$

and

$$\begin{aligned} W_u^2(\varepsilon) \quad &= \max_{k_l,\tilde{o}_f} \left[-1 + \rho(1-x)(1-\delta) + \rho x\theta\right] k_l - \tilde{o}_f + \\ &\rho(1-x)\mathbb{E}_\psi\left(\Pi^3(\varepsilon, k_l, \tilde{o}_f) + (1-\delta)k_l + \sum_{k=1}^{K} \pi_{ik} W^3(\varepsilon_k, k_f, o_f)\right) + \rho x\theta \mathbb{E}_\psi(k_l + \tilde{o}_f). \end{aligned}$$

Finally, the value of a type 3 firm is denoted as $W^3(\varepsilon, k_{f,-1}, o_{f,-1})$, defined as

$$\begin{aligned} W^3(\varepsilon, k_{f,-1}, o_{f,-1}) \quad &= \max_{k_l, i_f^-, i_f^+} -k_l - i_f^+ - \theta i_f^- + \rho(1-x)\mathbb{E}_\psi\Big(\Pi^3(\varepsilon, k_l, \tilde{k}_f) + \\ &(1-\delta)k_l + \sum_{k=1}^{K} \pi_{ik} W^3(\varepsilon_k, k_f, o_f)\Big) + \rho x\theta \mathbb{E}_\psi(k_l + \tilde{k}_f). \end{aligned} \tag{B.13}$$

This firm faces no upgrading decision.

3 Robustness analysis

We present a robustness analysis of our main findings in Table C.3. The table has the same structure as Table 3.4 in the main text. We perform four robustness checks. For each case, we recalibrate the baseline economy and then perform our main experiment, in which we eliminate border delays. For every robustness check, Table C.3 shows two columns, (i) the recalibrated economy with an average import delay of 13.8 days, and (ii) the change in key moments when delays are eliminated. The values in the upper half of the table are normalized by the baseline economy results for each case.

The first robustness exercise is the case where labor is supplied exogenously. The increase in the wage rate following the removal of border delays does not exert an income effect in this model and labor supply remains unchanged. Relative to our result in the main text this implies that the output effects of eliminating border delays are larger.

The second robustness check concerns the elasticity of substitution between different types of capital. This was equal to $\sigma = 0.5$ in the baseline. In Table C.3 we consider the case of $\sigma = 1.5$. Our results are hardly affected by this change. The reason is that even with $\sigma = 1.5$ type 3 firms continue to use both types of capital. Only for very high levels of substitutability between types of capital could firms forfeit the use of foreign capital.

Third, we study the implications of making foreign capital investments fully reversible. In the main text, negative investments of foreign capital in place are penalized, there is a markdown for selling existing foreign capital in place, reflecting capital specificity. Eliminating this cost implies that the selection margin of the benchmark solution is much less distorted. Following the removal of border delays, there is only a relatively small increase in the number of type 3 firms and their employment share. At the same time, there is a significant decline in the total number of firms. Because the wage rate increases, total labor supply falls, yet ceteris paribus all firms increase their factor demand due to the removal of the friction. To clear the labor market, M^* and thus the total mass of firms must fall. This channel is more pronounced than in the baseline economy because when foreign capital is fully reversible, the distribution of output among type 3 firms is initially much less skewed towards high productivity firms than in the benchmark economy (this was shown in Figure 3.8). The large output gains implied from enabling more low to medium productivity firms to choose to become type 3 firms is largely already realized in the economy without irreversibility.

Finally, we study how changes in θ affect our main result. This parameter determines the fraction of capital which can be recuperated by firms in terms of exogenous exit. It also governs the degree of capital specificity and is used for the markdown when selling foreign capital in place and is thus related to the previous exercise. Increasing θ to 0.95 does not have a big impact on our quantitative results, as shown in the last two columns of Table C.3.

	$N^s = 1$		$\sigma = 1.5$		reversibility		$\theta = 0.95$	
Border delays	Yes	No	Yes	No	Yes	No	Yes	No
Aggregate output	1.00	1.23	1.00	1.12	1.00	1.01	1.00	1.12
Local capital	1.00	1.27	1.00	1.08	1.00	1.05	1.00	1.16
Foreign capital	1.00	2.24	1.00	2.36	1.00	1.52	1.00	2.00
Outstanding orders	1.00	0	1.00	0	1.00	0	1.00	0
Labor supply	1.00	1.00	1.00	0.93	1.00	0.92	1.00	0.92
Wage rate	1.00	1.14	1.00	1.11	1.00	1.04	1.00	1.12
Mass of firms	1.00	1.03	1.00	0.90	1.00	0.84	1.00	0.85
Fraction of type 1 firms	0.48	0.35	0.55	0.44	0.52	0.44	0.50	0.38
Fraction of type 2 firms	0.27	0.24	0.25	0.25	0.30	0.31	0.28	0.27
Fraction of type 3 firms	0.26	0.41	0.20	0.31	0.18	0.25	0.22	0.35
Emp. share type 1 firms	0.31	0.09	0.34	0.12	0.32	0.18	0.31	0.10
Emp. share type 2 firms	0.19	0.09	0.18	0.10	0.20	0.15	0.18	0.09
Emp. share type 3 firms	0.50	0.83	0.48	0.78	0.49	0.67	0.51	0.81

Table C.3: Robustness analysis