Chapter 2
Drug Trafficking As Illegal Supply Chain—A Social Simulation

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Abstract Cocaine trafficking is starting to get modeled by supply chain theory. Supply chain theories are described in many economical papers. These theories are however not directly usable in analyzing illegal supply chains. In this paper we investigate the difference between legal and illegal supply chains. Where the difference of the supply chain lies in two factors, these are trust and risk. Here we model a cocaine trafficking supply chain based on legal supply chain theory. This model will be copied and adjusted with theoretical concepts that are inherent to an illegal supply chain. Comparison of the results of the two models showed that differences in those factors lead to differences in the supply chain, such as clustering and efficiency.

Keywords Illegal supply chain · Cocaine trafficking · Trust · Risk

Introduction

The Netherlands is part of the cocaine trafficking business. This is an illegal business that connects cocaine producers in South America to consumers all over the globe. It starts in countries such as Colombia, Peru and Bolivia where coca leaves are farmed and refined to cocaine. This product is transported to various continents, including Europe. The Netherlands and Spain seem to be the main entry points for the drug [15]. The criminals in these countries transport the goods to other European countries

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after importation. Transportation of such large quantities of illicit drugs comes with high criminal activity.

The criminals take advantage of legal transport, real estate and bribe civilians. These undermining actions have a negative effect on public well being and safety. Although less common than in the past, there is still violence among criminals [5]. The strategy applied in the past decades by America had the goal of supply reduction, by eradicating plantations, destroying drugs labs and capturing or killing cartel leaders in South America and Mexico. A positive effect happened in the United States which saw an increase in cocaine price and a decreased drug consumption. However there seem to be more negative effects, as eradicated supply routes have been displaced, creating criminal activities and in some cases more homicides in other regions. The tactic of Mexican police to capture or kill the leading drug dealers, i.e. kingpin strategy, has lead to the fragmentation of large criminal organizations and a massively increased homicide rate [7]. After these events the small number of large criminal groups (cartels), who are based on ethnic ties and are hierarchically structured, broke down into many small independent criminal syndicates who see themselves as entrepreneurs and are based on friendship, kinship and ethnic networks to select partners [5]. These newly formed smaller groups work together to form a supply network that provides drugs all over the globe. In recent decades this market has shifted to Europe and the questions for authorities how to deal with these illegal activities remain. Especially for the Dutch National Police, who are stakeholders in this project, as the Netherlands is a transit country within this illegal supply chain [15, 17]. Knowing more about the illegal supply chain will help authorities make better decisions, when it comes to applying strategies against the criminal world.

To gain insight in the workings of the illegal cocaine trafficking supply chain, we cannot straightaway use current supply chain (SC) theories [2]. These are theories, like the role of trust in SC responsiveness [9] and building a resilient SC [4] that are based on analyses of legal businesses. There are some crucial differences between a legal and an illegal SC. Since there is no official regulatory instance, like contracts or the government, within criminal networks, cooperation is based on other factors such as trust [14]. Performing illicit tasks contains the risk of getting caught by the police, thus risk management strategies are also different in criminal networks [2]. These two factors, trust and risk, will be taken into account for the illegal SC model. We will propose a comparison of two models, one model of cocaine trafficking where the SC component is based on legal supply chain theory. The second is a copy with some adjustments based on theoretical concepts inherent to illegal SCs. These models will then be compared to explain qualitative differences between a legal and illegal SC. Differences regarding the SC growth, dynamics of connections and efficiency.

The next section will describe legal SC theory and a simulation with trust based on legal SC theory. The third section describes the important aspects of cocaine trafficking such as: trafficking, quality, trust and risk. The fourth section describes the proposed model in detail. The fifth section shows results and comparison of the model. In the last section we end with a discussion.

Supply Chain

The term supply chain, although frequently used in contemporary times, is relatively new within economics. It was first coined in the early 1980 as management term. The idea is that individual companies replace the priority of self-interest and personal profits gain, to create an efficient organization with their suppliers and clients [4]. SC management would manage the process from raw materials to delivering the costumer, aiming at an efficient product flow. There are many SC models [11]. However they are not directly the most interesting for this project. They do not take into account the factors of trust and/or risk.

Simulation of a Supply Chain with Trust

Jalbut and Sichman [10] give a simulation of a SC with trust. We will use this simulation as basis for our simulation, as trust is one of the important factors to include in the simulation. Agents in the SC send orders, that take a few steps to arrive, to their supplier. The supplier, upon receiving an order, sends a shipment if he has enough stock. This shipment arrives a few steps later and is received by the client. The trust in the supplier is defined by the historical ratio between the orders placed and the shipment received (Eq. 2.1). In the formula i is the client, j the supplier, the current simulation step is denoted with n, S_{ji} is the shipment received and O_{ji} is the order send. The formula takes into account the time it takes to receive the shipment after sending an order, by mapping the shipments 6 ticks later.

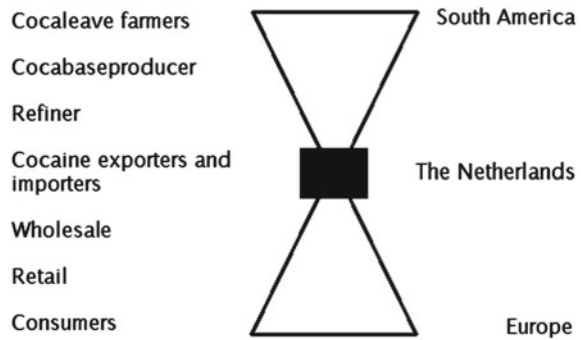$$Trust_{ij}(n) = \sum_{r=6}^{n} S_{ji}(r) / \sum_{r=1}^{n-6} O_{ij}(r) \tag{2.1}$$

The agents in the simulation search for new suppliers by random chance. They ask their peers for trustworthy suppliers. They will choose suppliers with the highest trustworthiness.

Cocaine Trafficking

The Netherlands As Transit Country

Since the National Dutch Police are stakeholders in this project, we look at the role of the Netherlands in cocaine trafficking. Research states that organized crime in the Netherlands takes the role of a transit-hub (Fig. 2.1).

Fig. 2.1 Based on Zaitch [17]

Cocaleave farmers

Cocabaseproducer

Refiner

Cocaine exporters and importers

Wholesale

Retail

Consumers

South America

The Netherlands

Europe

The chain starts in South America where the coca leaves are farmed and refined to cocaine. Most of the pure cocaine for the European market is transported overseas to the Netherlands and Spain. In the Netherlands the cocaine is partly consumed, but the larger amount is distributed to other countries such as Germany, Belgium, United Kingdom and Scandinavia. The form of the figure indicates that the SC starts with many coca leave farmers, who are widespread. The number of people working on it decreases every step from there on. At the cocaine exporters and importers level the number is the smallest and the goods are bundled into larger packages. After import the number of criminals in the process increases and the goods are spread out. Until they reach the consumers who can be all over the continent.

Drugs Trafficking

To create a complex simulation we take quantity, quality and pricing into account. These aspects influence each other as higher quantity usually means higher profits but also higher costs. An increase in quality can also increase the profits but the desired quality may not always be available.

Quantity is dependent on the SC level. Individual farmers only transport a few kilograms. In international transport, ships are mainly used. These ships contain containers filled with hundreds of kilograms of cocaine. Upon arrival in a transit country these shipments can be split among wholesalers, who in turn split it to retailers in even smaller amounts. At the end of the chain, consumers only buy several grams [15].

In the process of trafficking purity of cocaine can be decreased by cutting. Against common beliefs cutting is not performed by retailers, using harmful substances like cleaning products, brick dust and ground glass. Instead it is most often done at production level or at import level, without the goal of harming consumers [3]. According to Broséus [3] the changing of quality, cutting, is performed either at production level or directly after import, at wholesaler level. The purity determines to which countries it can be shipped as customers in different countries are satisfied

with different levels of purity [15]. Data from the EMCDDA also indicates highly varying purity in different European countries [6].

Pricing of the cocaine is mainly dependent on the SC level. The price per kilogram increases substantially for each level. After production and refinement in South America a one kg brick of cocaine is worth $800. At international export level in Mexico this price has increased to $34.700 per kg. After import in the country of destination it becomes even higher with $120.000 per kg for the U.S [1]. This difference in pricing should be introduced in the simulation to represent the income of the agents in a more realistic way.

Trust and Risk Assessment

There is a difference between legal and illegal SCs within the concepts of trust and risk. In legal SCs companies can make contracts with each other to form cooperation and prevent risks. In criminal networks formal contracts are not a possibility. Therefore there must be other bases of cooperation. Analysis by Lampe and Johansen [12] on smuggling networks, indicates that cooperation between criminals is highly based on trust. They propose many forms of trust and see the lack of trust as deterring cooperation among criminals, as this increases extortion and threats. In Lotzmann and Neumann [13] we can see a criminal drug dealing group dismantling itself because of the loss of trust among members. There was an event of distrust in a person, this lead to punishing reactions of others. Eventually leading to liquidations.

Risk evaluation is done by criminals in the cocaine trafficking business [16]. One of the main priorities is to not get caught as this leads to personal loss or monetary losses. The risk may prevent criminals from acting immediately and delay their operations. On different levels of the SC there is a varying amount of risk [16]. However this goes out of the scope of this paper. With larger shipments the risk is higher as they are more easily detected and the potential loss is larger. This is different from a legal SC, where the risk of capture by authorities is absent, if the paperwork is fine of course.

Conceptual Model

This section describes the full model in detail. To promote reproducibility the model is available through GitHub[1] and the GitHub contains an Overview, Design concepts, and Details document (ODD) [8]. The model uses the legal SC implementation with trust, by Jalbut and Sichman [10], as a basis. The model's domain is illegal cocaine

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[1]https://github.com/maartenjensen/Social-simulation-illicit-supply-chain. Branch: *SSC2019*, commit number *9870ed3*.

trafficking through Europe. From this domain we use qualitative data to provide the model's concepts and quantitative data to provide some parameter settings.

Purpose

The purpose of this model is to give answers to the research question: *What is the difference between a legal and illegal supply chain?* The legal SC is the standard model. We create the illegal SC model by making two adjustments to the standard model. One adjustment is based on trust relations, the other based on risk as these are both prominent factors in an illegal SC. A comparison of the results of both models will be used to answer the question.

Entities, State Variables and Scales

The entities in the simulations are agents, countries, orders and shipments (Fig. 2.2). They are divided in 5 levels in the SC: producers (P), internationals (I) , wholesalers (W), retailers (R) and consumers (C), based on Jalbut and Sichman [10]. *Producers* are their own suppliers and can decide their own production rate. The quality is fixed for a producer, either 40 or 60. The higher quality is sold for 20% more money. *Internationals* have the highest shipment quantities as they send their shipments overseas. *Wholesalers* have the option to convert high quality to low quality, for each high quality they have they get 1.5 low quality. Quality is purity and as an example 2 kg of 60 purity, would leave 3 kg of 40 purity. They perform this cutting whenever they do not have sufficient low quality for an order and have some high quality to cut.
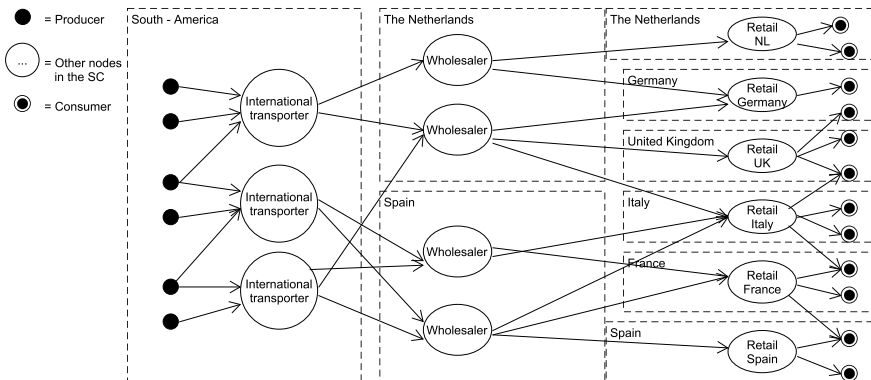

Fig. 2.2 Simulation overview: showing the layout of the entities. Arrows are a supply line and shows the direction of shipments, orders go the other way around

Retailers shipment quantity is the lowest as they send to the consumers. *Consumers* do not have clients as they consume the goods themselves. They have a fixed quality and consumption rate per tick. They are removed from the simulation when they cannot consume for a fixed amount of ticks. All the other agents are removed when they are bankrupt or when an amount of time (104 ticks, 2 years) has passed with no incoming or outgoing shipments for that agent. The pricing grows the further up the chain (towards the consumer). These price differences, *selling price*, are based on the relative price differences in Basu [1]. The general formula for the price of a shipment is represented by *price = selling price* $\cdot (quantity_{q=low} + quantity_{q=high} \cdot$ 1.2), where the high quality is multiplied by 1.2 to represent the 20% increase in price for high quality.

Countries spawn agents of the corresponding SC levels (Fig. 2.2). Since both the Netherlands and Spain are seen as transit countries they contain wholesaler agents. Dependent on the SC level the agents' horizontal position is decided. Their vertical position is dependent on the country. The consumers in European countries crave different amounts of quality [6].

Orders and Shipments take three steps to reach the destination. Orders travel from client to supplier, shipments from supplier to client. They contain the required goods, this is the amount of quantity for each required quality. Shipments also contain the price to be paid by the client. Agents use a learning function to send orders, which makes the orders and shipments arrive in a stream instead of impulsive.

Scheduling

The scheduling of the model is described by pseudocode in Algorithm 1.

Algorithm 1: Model schedule, based on [10]

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1 **foreach** *tick* **do**
2   *Agent:* Pay living cost & removal of bankrupt nodes
3   *Country:* Spawning of new agents
4   *Shipments:* Move one step further
5   *Orders:* Move one step further
6   *Agent (consumer):* Receive income
7   *Agent:* Choose new suppliers and clients
8   *Suppliers:* Receive orders **AND** send shipment to client
9   *Consumer:* Consumes
10   *Clients:* Send order to supplier
11   *Producer:* Create a shipment for himself
12 **end**

Design Concepts

The purpose of the model is creating two SCs, a legal and illegal SC that can be compared. The objective of each agent in the SC is to survive by gaining profits. This is done by being able to supply the clients and keeping the stock low. The agents adapt their orders to suppliers based on the amount of goods they require. When there are not enough goods available they will search for new suppliers. When there are sufficient goods available they can search for additional clients. They cannot send shipments directly, however they can connect to new clients. When connected, the clients can start to send orders to the suppliers. A new supplier with directly a good response of shipments can become the main supplier for that client. These micro actions can let a SC emerge since consumers will consume and find out they need suppliers. They find retailers who in turn have to find wholesalers. This process continues until the producers are reached who start producing and send shipments. These shipments eventually reach the consumers. The agents learn from interaction with their suppliers, i.e. how often they send their shipments, this is the definition of trust in this model. The agents only have interaction with neighboring agents, thus only the direct suppliers and clients. For choosing suppliers and clients they look at the trust relation of agents at the same SC level. Stochasticity is used at a few places in the model. The agents are initialized at a random position in their country. New possible clients and suppliers are ordered based on trust but random when they have the same trust level. The possibility of sending a shipment in the illegal SC is stochastic. The starting stock quality and security stock quantity is stochastically determined. For consumers the consumption rate is stochastically determined.

Legal Versus Illegal

Trust The clandestine nature of illegal trafficking makes clients and suppliers not openly visible. While legal suppliers and clients can usually be found through the internet or commercials. The illegal SC agents try to be as discrete as possible. The illegal SC model takes this into account by limiting the visible clients and suppliers. An illegal agent always has the closest supplier and the closest client. The chance of being able to know other suppliers and clients is given by ρ determined by Eq. 2.2. It takes into account the vertical position between the agent y_i and a client or supplier y_j, and divides the distance by the grid height $h = 50$. The minimum returned probability is given by $\alpha = 0.1$. The *probability multiplier* $\beta = 0.5$, decreases the total probability.

$$\rho = max(\alpha, (1 - min\left(1, \frac{1}{\beta} \cdot \frac{abs(y_j - y_i)}{h}\right))) \tag{2.2}$$

Risk One difference between the legal and illegal SC is the possible risk of getting caught by police. This is the case for participants in the illegal SC. Criminals have to wait for the right moment, where they have the right transportation available and when they can evade the police. They cannot send shipments all the time, even when they have enough stock. Therefore a shipment interrupt probability is introduced. It is set at 0.4, this means that there is a 40 percent chance in the illegal SC that an agent can send a shipment. If the agent cannot send a shipment the corresponding order is delayed and added to other delayed orders. The agent sends a shipment when there is no interruption and when there is a new order, this shipment will take all the delayed orders and the new order into account. The client will receive this shipment and compares this with the matching order (6 ticks back). The excessive quantity will be added to the received shipments with a penalty of 0.5.

Results

Simulation Initialization

We show the behavior of the simulation in more detail in this section. We analyze the micro behavior of agents and compare this with the model's design. The SC will form from the consumers to the producers. Since consumers are the first to deplete their stock and crave more goods, they will receive the goods from retailers and then the retailers will not have enough stock. This behavior propagates until it reaches the producers, who will start a production line.

Figure 2.3 shows a part of this process in which an international finds a producer in a legal SC. Figure 2.3a shows tick 11, with orders (blue orbs) coming from the wholesaler in Spain with id:15 (W) to the international with id:8 (I). The orders from wholesaler 15 contain both low quality and high quality requests. In Fig. 2.3b the orders are processed by the internationals (7 and 8) and they send shipments back. Since they both have low quality in their stock and low quality is in the orders, they send a shipment of low quality (dark yellow orb). The next step both internationals (7 and 8) realize they do not have enough stock and search for a producer (P). Likewise the producers search for an international as they have enough stock, thus at Fig. 2.3c we see the connections are made. The connections start with trust 0 indicated by red, a trust of 1 is indicated by a green line. The internationals send an order straight away. After a few ticks (Fig. 2.3d) the orders of the internationals have reached the producers, the producers (1 and 3) send a shipment and start producing shipments for themselves to meet the demand. Producer 3 sends a high quality shipment and produces high quality goods, while producer 1 does this with low quality. These shipments can be seen at the left of the producer and arrive three steps later. This shows the processes of the simulation at micro level, in the next experiment we show the macro level behavior of the model.
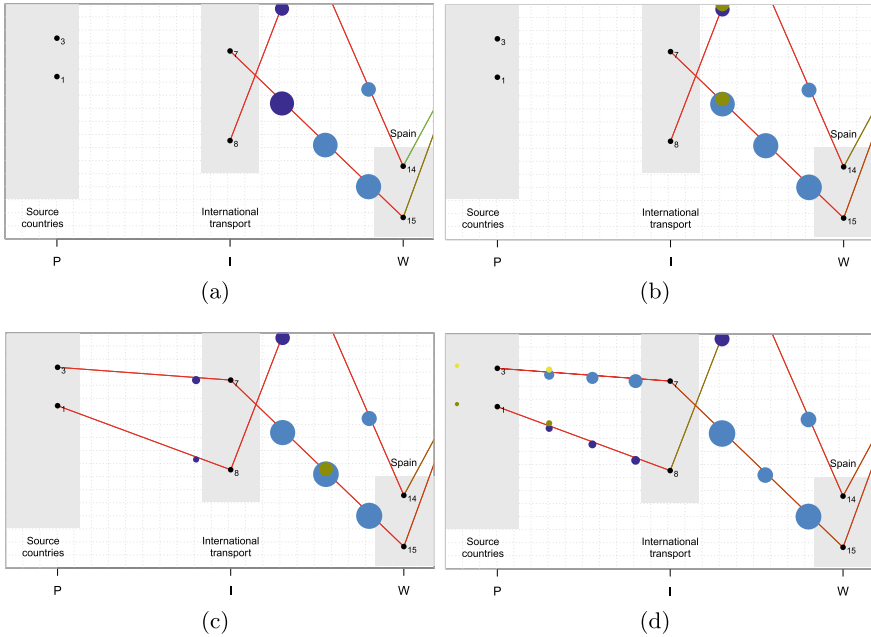
Fig. 2.3 Legal SC initialization: **a** Tick 11; **b** Tick 12; **c** Tick 13; **d** Tick 16 Black dots are agents with their ID displayed, the lines are connection between agents, blue orbs are orders (go to the left) and yellow orbs are shipments (go to the right)

Legal and Illegal Comparison

For the comparison we have run both the legal and illegal model for 1000 ticks. The input parameters are as given by the GitHub code, the same as in the initialization runs. It can be expected that in both runs SC networks will form from producers to consumers. However they most likely differ in composition, with a legal SC network being more spread out and the illegal one more clustered. The trust will most likely be less for the illegal SC as shipments get delayed.

Figures 2.4 and 2.5 show respectively the formed legal SC and illegal SC. An immediate difference that can be seen is the difference in density, where the legal supply chain is much more dense. This has to do with the increase of agents and the increase in connections between those agents (since they are able to make more connections). When we look at the colors for the trust level, we can see that the legal supply chain has many red colored connections. However also brighter colored green connections, indicating higher trust levels. This can be explained by the absence of shipment interruptions, where sending a shipment is only dependent on the stock of a supplier, which makes it easier to send shipments on time. With no interruptions the stock can be maintained relatively easily. When there are interruptions it is harder to keep stock, the clients do not get enough shipments and therefore make larger orders.
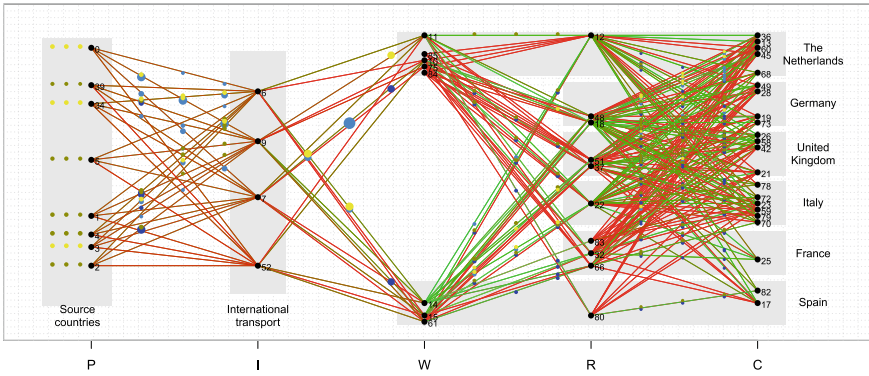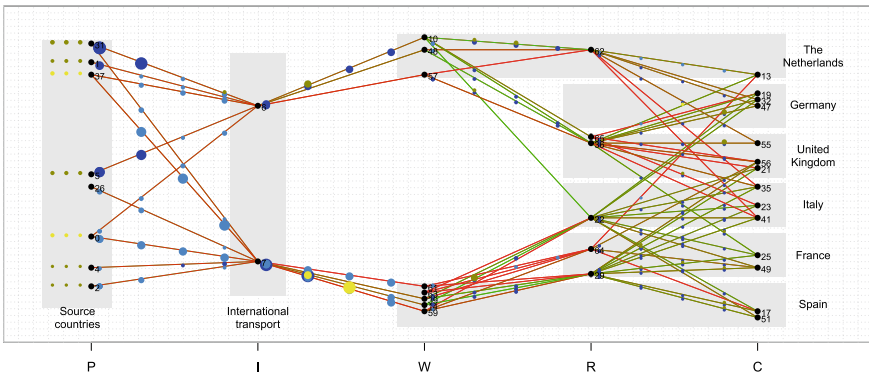
Fig. 2.4 Legal supply chain—At Tick 1000

Fig. 2.5 Illegal supply chain—At Tick 1000

This can be seen in the illegal SC between the producers and wholesalers (there are larger blue orbs). The network of the legal SC is more evenly distributed, wholesalers from the Netherlands would deliver to retailers in Spain and vice versa. This does not happen in the illegal SC, where wholesalers of the Netherlands tend to supply retailers from Germany, United Kingdom and Italy. While wholesalers from Spain tend to supply retailers from France, Italy and the United Kingdom. The retailers from their own countries are not there, they became bankrupt at an earlier tick. Possibly by their lower number of *possible clients* as they only have one neighboring country. At the international level the SC is the smallest in terms of number of agents, going left from the wholesalers the number of agents expands. This roughly approaches the hourglass form in Fig. 2.1.

The plots Figs. 2.6 and 2.7 show some differences in the average wealth among agent types. For most SC levels the average money is comparable. Producers have the least money, this is expected since they make the least money from selling. The retail agents earn a bit more, they do have a higher selling price but only sell small
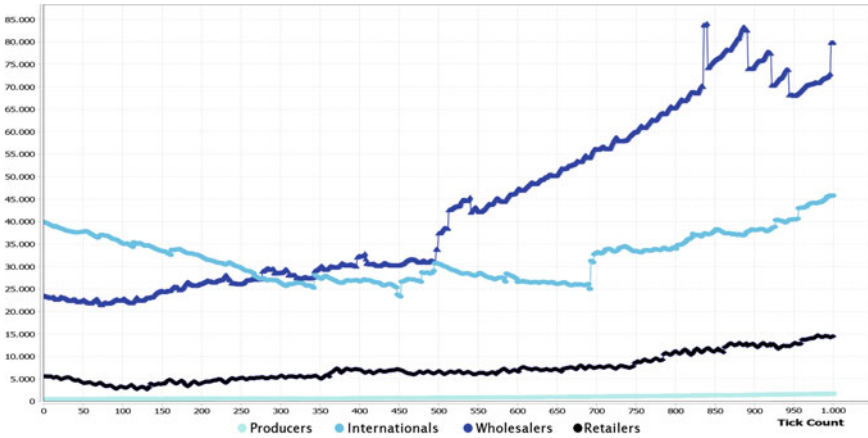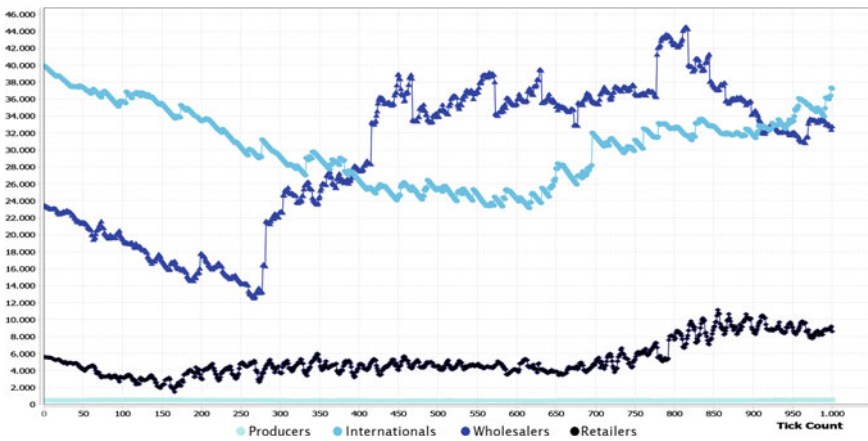
Fig. 2.6 Legal SC money average

Fig. 2.7 Illegal SC money average

quantities. Combine this with their higher living cost, since labour cost in Europe is higher than in Colombia. The internationals and wholesalers make the most money, as they move large quantities and are in a high selling price. In the legal supply chain we can see the internationals earning a lot of money after tick 500, probably since a stable network has been established. This allows the internationals to have a constant stream of goods from multiple suppliers and able to sell to multiple wholesalers. This does not happen in the illegal SC, probably since it is not stable enough. The illegal average wealth seems to fluctuate more due to a combination of a lower amount of agents and the interruption in shipments. The interruptions in the illegal SC introduce less frequent but higher monetary gains.

Table 2.1 Summary comparison between the legal and illegal SC

Legal SC	Illegal SC
○ Generally a higher trust level	○ Generally a lower trust level
○ Retailers are spread through all countries	○ Not all countries have retailers
○ Trade routes are spread out	○ Trade routes seem to bundle more
○ More efficient thus it can satisfy more consumers	○ Less efficient thus it can satisfy less consumers
○ Few goods are lost because of agent removal	○ Some goods are lost because of agent removal
○ Smaller orders thus smaller shipments	○ Larger orders thus larger shipments

There is also a difference between the legal and illegal SC regarding the produced goods and lost goods. The legal SC has a higher produced goods and consumed goods throughout the run. The amount of removed goods, due to bankrupt agents is relatively low. The illegal SC has lower produced goods and consumed goods and more removed goods than the legal SC. This indicates that the illegal SC has less efficiency. Table 2.1 shows the conceptual results based on the simulation results.

Discussion and Conclusion

By modeling cocaine trafficking as a SC with certain aspects adjusted, a difference in trust and risk. We get the results seen in Table 2.1. The illegal SC seems to reproduce trends of the real world.

The creation of this model brought many possibilities for improvements forward. In the simulation all the agents are syndicates, thus not explicitly modeled as individuals. This would be interesting to see what for example the kingpin strategy [7] would do. The simulation can be adjusted in such a way that agents in the SC can be taken out by the police. For example a large wholesaler that, after a police intervention where they capture the leader, splits up in two smaller wholesalers. Each of the wholesalers having part of the supplier and clients. It would be possible to introduce rivalry or cooperation among these separated wholesalers.

The pricing in the simulation is currently fixed, with variations at different levels and for a higher quality. The agents are not able to vary the prices themselves. Allowing this would show interesting results regarding the tactics used by agents to thrive in the SC. This can be analyzed under different circumstances. Additional tactics could be the choice of shipment size, frequency and concealment level, to prevent detection however increasing costs.

Currently the simulation goods are going through the SC on a demand basis. Since it is based on Jalbut & Sigman's supply chain model [10]. However described by Vermeulen et al. [15] there are cases of an overflow of the drug market. Giving the suppliers the ability to push more quantity may change the behavior of the SC as well.

This means other agents have to search more actively for more clients. With many agents there will be a large amount of competition, which will have other effects, possibly decreasing the prices. Using other economical models we could model this push dynamic.

This model can be used as a basis for illegal SC modeling. However there is still much to do, which is to be seen as it already generates many interesting questions.

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